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MINUTES
OF THE TWENTY-FIFTH
EXPLOSIVES SAFETY SEMINAR

VOLUME II

Explosives Safety Board
DEPARTMENT OF DEFENSE

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Anaheim Hilton Hotel
Anaheim, California
18-20 August 1992

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Sponsored By
Department of Defense Explosives Safety Board
Alexandria, Virginia

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PREFACE

This Seminar is held as a medium by which there may be a free exchange of information regarding explosives safety. With this idea in mind, these minutes are being provided for your information. The presentations made at this Seminar do not imply indorsement of the ideas, accuracy of facts presented, or any product, by either the Department of Defense Explosives Safety Board or the Department of Defense.

DAVID K. WALLACE
Captain, USN
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TWENTY-FIFTH DDESB EXPLOSIVES SAFETY SEMINAR

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Risk Assessment Methodology to Evaluate Public Risk for Cleanup of Ordnance at Formerly Used Defense Sites

Prepared For

Department of Defense Explosives Safety Board

Twenty-Fifth DoD Explosives Safety Seminar

18-20 August 1992

By

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INTRODUCTION

The Defense Environmental Restoration Program (DERP) is congressionally mandated (Public Law 99-190 and 99-499) and directs the Secretary of Defense to carry out a program of environmental restoration. This mission of environmental restoration has been assigned to the U.S. Army Corps of Engineers (USACE).

The DERP Program allows for the restoration of both active Department of Defense (DoD) sites as well as sites that were formerly used by a DoD component. The program for restoration of active installations is commonly referred to as the Installation Restoration Program (IPR) while the program for restoration of former installations is known as Formerly Used Defense Sites (FUDS).

The DERP goals are (1) to provide for the identification, investigation and cleanup of contamination of hazardous and toxic wastes, (2) to correct other environmental damage which create an imminent and substantial endangerment to the public or the environment, and (3) to dispose of unsafe buildings and structures. The purpose of this paper is to discuss item 2 above with regard to unexploded ordnance on formerly used defense sites.

The Corps of Engineers has been actively establishing a data base of sites meeting the criteria of the DERP-FUDS. That inventory currently stands at over 7,050 sites that fall into the previously mentioned categories of contamination. Of these 7,050 sites, there have been identified 900 formerly used sites that have a high potential for ordnance contamination. With this magnitude of ordnance contaminated sites, it became evident to the USACE, that some mechanisms for evaluating the degree of risk and prioritizing any investigation and remediation effort would be necessary. In addition, due to the potential programmatic cost of the effort, some method(s) must be adopted to manage the public risks to an acceptable level.

RISK ASSESSMENT FOR PROJECT PRIORITIZATION

In the initial stages of development of a procedure to evaluate levels of ordnance contamination and prioritize remediation, it became evident that the real issue was public exposure to ordnance and explosive waste (OEW). Ordnance, unlike Hazardous and Toxic Wastes (HTW), was generally not mobile, in effect it had no medium such as groundwater for transport (the exceptions being erosion or ocean transport). The public generally had control of their exposure to OEW, in effect if you did not touch or disturb the OEW the risk was minimal.

The AR 385-10 and MIL-STD 882B establish policy and procedures for evaluating the risks associated with the operation of Army and DOD facilities and equipment. This procedure evaluates the probability of occurrence, as well as the severity of an occurrence. The combination of the two criteria in the form of a risk matrix provide management with a qualitative tool to evaluate the relative risk associated with operation of the particular facility or equipment.

In considering methods for evaluating OEW sites a similarity emerged in that the severity of a mishap was directly related to type of OEW, and the probability of a mishap was relevant to the potential for accessibility of the OEW to the public. Applying existing Army and DOD criteria and method to evaluate public risks to OEW would greatly simplify the acceptance of the method plus the method was a proven technique for evaluating risks. The primary differences were (1) that the risks being evaluated were not worker related, they were the general public and (2) the evaluation was not of facilities or equipment but of a piece of land.

HAZARD SEVERITY

In the development of the hazard severity, five general categories of EXO were identified. These categories included (1) conventional ordnance and ammunition (small arms ammunition to bombs), (2) pyrotechniques (incendiary, flares, etc.), (3) bulk high explosives (TNT, HMR, RDX, etc.), (4) propellants (solid and liquid), and (5) chemical agents/weapons (GB, VX, HD, BZ, etc.). Within these 5 categories, values were assigned from 0 to 25 based upon the expected hazard associated with public exposure to particular ordnance item. These values were subjective and based upon engineering experience and judgment of the USACE ordnance engineering and explosive safety staff. The Hazard Severity Table is provided by Table A.

TABLE A

HAZARD SEVERITY

Description Value	Category Level	Value
CATASTROPHIC	I	≥21
CRITICAL	II	≥13 <21
MARGINAL	III	≥ 5 <13
NEGLIGIBLE	IV	< 5

HAZARD PROBABILITY

The hazard probability addresses area, extent, and accessibility of the OEW to the general public. The areas evaluated include (1) location of contamination (surface, subsurface, within pipes or vessels) (2) proximity to inhabited buildings or structures to the OEW site, (3) the number and type of structure (military, child care, hospital etc.), (4) accessibility of site to the public (i.e., barriers provided), and (5) site dynamics that could expose ordnance in the future such as erosion. Within these five categories and subcategories, values were assigned from 0 to 5 based on the potential exposure to the OEW. Again these values were based upon sound engineering, experience, and judgment of an ordnance engineering and explosive safety staff. The hazard probability table is provided by Table B.

TABLE B

HAZARD PROBABILITY

Description	Level	Value
FREQUENT	A	≥27
PROBABLE	B	≥21 <27
OCCASIONAL	C	≥15 <21
REMOTE	D	≥ 8 <15
IMPROBABLE	E	<8

RISK MATRIX

While the probability of occurrence and hazard severity assess the risk to the public, a risk matrix must provide guidance to management on actions or mitigative measures that should be implemented. The risk matrix for OEW was developed to provide environmental managers with environmental remediation recommendation. This Risk Assessment Code (RAC) matrix is shown in Table C. During the initial phases of development of the RAC, 76 OEW sites with good historical information were selected to use as a verification phase for the overall procedure. These 76 sites were independently evaluated using the RAC. Upon completion of this initial assessment, adjustments and refinements were made to better reflect the actual risks of OEW contamination. There was nothing scientific or statistical concerning the verification only practical application of the RAC procedure that has provided a significant level of confidence to the users of the RAC in actual field applications.

TABLE C

Probability Level		FREQUENT A	PROBABLE B	OCCASIONAL C	REMOTE D	IMPROBABLE E
Severity Category:						
CATASTROPHIC	I	1	1	2	3	4
CRITICAL	II	1	2	3	4	5
MARGINAL	III	2	3	4	4	5
NEGLIGIBLE	IV	3	4	4	5	5

RISK ASSESSMENT CODE (RAC)

RAC 1 Imminent Hazard - Emergency action required to mitigate the hazard or protect personnel (i.e., fencing, physical barrier, guards, etc.).

RAC 2 Action required to mitigate hazard or protect personnel. Feasibility study is appropriate.

RAC 3 Action required to evaluate potential threat to personnel. High priority confirmation study is appropriate.

RAC 4 Action required to evaluate potential threat to personnel. Confirmation study is appropriate.

RAC 5 No action required.

RISK ASSESSMENT FOR PROJECT ACTION ALTERNATIVES

The exact procedure for evaluating acceptable public risks are currently under development by USACE. The following discussion represents our intitial OEW risk assessment work for defining methodology to evaluate public risks. This work was performed by Southwest Research Institute, San Antonio, Texas, under contract to the USAEDH.

Definition of Risk.

a. Since risk encompasses several factors, the elements that comprise risk need to be defined. A mishap is an unplanned, undesired event that results in harm to people, equipment, property and/or environment. The mishap may have occurred at some time in the past. In many instances, a past mishap triggers the risk assessment. The mishap may also be potential, as in a hazards analysis, which investigates the risk potential and assesses control alternatives. Without a real, or potential mishap there is no risk. Each mishap has two components, the probability of the mishap and its severity. The probability is the likelihood that the mishap will occur during the life of the system, or the life of the site.

b. In its most simple terms, risk is the probability of mishap multiplied by the severity. For a site remediation operation, risk is not a single number. It has a different value for each ordnance item and for each element of the survey, removal, and remedial actions. An additional confounding effect is that risk contains a perceived risk factor in which the public can "feel" that the risk is greater, or smaller, than the calculated risk. For instance, the perceived risk of a terrorist attack is far greater than the real risk. Similarly, the perceived risk of hazardous waste is often greater than the real risk. Perceived risk should be considered in any remedial action where the public, or local government is involved and has a voice in the type and extent of remediation that is contemplated. Perceived risk is not considered in assessing the need for remedial action. That assessment needs to be made on a technical/statistical basis.

c. The probability of a mishap must be assessed to provide an indicator of the risk. Probability always relates to an interval of time. In the assessment of a facility it relates to the life of the facility. In an assessment of site it relates to the life of the site, or to some arbitrary span of time. Five categories of probability rating are provided in MIL-STD-882B:

(1) Category A - Frequent. "Likely to occur frequently."

(2) Category B - Reasonably Probable. Likely to occur several times during the remedial operation, or during the life of the site.

(3) Category C - Occasional. Likely to occur sometime during the remedial operation, or during the life of the site.

(4) Category D - Remote. "So unlikely it can be assumed that this mishap will not occur."

(5) Category E - Extremely Improbable. "Probability of occurrence cannot be distinguished from zero."

Definition of Severity.

a. Severity is the extent of damage, due to the mishap, to personnel, equipment, property, and/or the environment. Severity depends on the ordnance item, or the threat, the step in the remediation action in which the mishap is considered, and any severity-limiting control features that are incorporated into the remedial action.

b. Four categories of severity are established by MIL-STD-882B:

(1) Category I - Catastrophic. May cause death.

(2) Category II - Critical. May cause severe injury or severe occupational illness.

(3) Category III - Marginal. May cause minor injury or minor occupational illness.

(4) Category IV - Negligible. Probably would not affect personnel safety or health, but is a violation of applicable standards.

Definition of Exposure.

In risk assessment calculations the exposure is used for estimating the risk of transient events, such as the transit across an OEW site, or in assessing the risk of a phase of the remedial action operation. Exposure is the time that personnel, equipment, property, or environment are under the potential influence of the mishap. Exposure may be measured by the timewise intersection of the projected damage area with the exposed personnel, property, or equipment. Exposure assumes a transit of the energetic source, personnel, or the equipment through an area in which a mishap could occur. In general, the exposure is a function of the energy source, a proximity to the threat, the transit time, the likelihood of initiation of the ordnance item, and the cover protection that is afforded by natural and artificial barriers.

Establishing the Need for Remedial Action.

a. The formalized procedure for project approval and initiation entails the following elements:

(1) Inventory Project Report (INPR) by geographic Division. This report delineates and justifies the need for remedial action. It is typically initiated and approved by the Commanders of geographic Divisions.

(2) The U.S. Army Engineer Division, Huntsville (USAEDH) conducts a formal review of the INPR. If USAEDH concurs, USAEDH Safety develops a Risk Assessment Code (RAC) and a Program Estimate.

(3) Project approval is by USAEDH. Approval is followed by a work authorization directive (WAD).

b. In the final analysis, the need for remedial action depends on the risk to the population that intrudes on an OEW site. Many sites that were formerly used to manufacture, process, store, or test ordnance items are being absorbed into the infrastructure of cities, suburbs, and towns. As the land values increase there is a commensurate increase in risk for the population. Often, the incentive for the assessment is a mishap in which someone is harmed by an encounter with ordnance and explosive waste (OEW).

c. The need for remedial action is established by a risk assessment. The culmination of this risk assessment is the development of Risk Assessment Code (RAC). The RAC is a quantified expression of the risk associated with the hazard and is calculated by combining the elements of the hazard severity and the mishap probability. Given that a RAC is developed, the need for the remedial action is established by a set of RAC criteria which identifies the acceptability of the risk. These criteria are:

(1) RAC 1 - Unacceptable level of risk.

(2) RAC 2 - Undesired level of risk which must be controlled.

(3) RAC 3 - Acceptable level of risk if adequate controls are effected.

(4) RAC 4 - Acceptable level of risk without controls.

(5) Remedial action is indicated for RAC 1, RAC 2, and RAC 3. Remedial action is not needed for RAC 4.

Selecting the Proper Action.

The definition of the level of remediation required is somewhat subjective. The RAC provides an approximate criteria for assessing if remedial action is needed. An assessment is still

needed on the type, and the amount, of remedial action. Several factors enter into the decision of the proper remedial action:

(1) Identify potential risk items. The greater the number of items, the higher the risk, the more thorough is the remedial action that is indicated. The type, or types, of items under consideration are the primary drivers in identifying the remedial options, since very lethal items severely drive the remedial options, and very innocuous items may require no action.

(2) Identify remediation options. The remedial action options are ranked from least to most severe: (1) No Action: (2) Fencing; (3) Land Use Restriction; and (4) Removal of OEW. "No action" produces no reduction in risk. "Removal of OEW" produces the greatest reduction in risk.

(3) Select proper remedial action. Ideally, the selection of the proper remedial action should be directly commensurate with the cost of the remediation effort. Often the cost of the remediation is greater than the dollar worth of the risk reduction. A management decision, then, is needed to select the proper level of remedial action that provides a real, and proper, level of risk reduction at an affordable cost. It is also recognized that public pressure of perceived risk tends to drive the remedial option selection toward the use of clearing the land of all OEW.

(4) Establish sufficiency of cleanup. The criteria for "clean" is established by the risk analysis. After the remedial action has been accomplished, the effectiveness of the remediation is compared to the pre-established level of cleanup.

Selection of Risk Assessment Methodology.

a. It is assumed that the reader is generally conversant with risk assessment methods. Several acceptable risk assessment methods are delineated in MIL-STD-882B. Each risk assessment method has its strengths and weaknesses. Typically the choice is less of utility than it is of familiarity by the analyst. Most of the methodologies can be used in a quantitative or a qualitative evaluation. Typically, the fault tree analysis, or some similar method, is most easily used for a quantitative analysis. The failure modes and effects analysis, or some similar method, is most easily used for a qualitative analysis.

b. Some analysis methodologies, such as the worst case scenario, are more easily adapted to an operation oriented problem. In such an analysis each operational step and decision is delineated sequentially and analyzed for what can fail in terms of operations and decisions. Such an analysis is particularly useful for defining and assessing training.

c. Often the analysis method is selected on the basis of failure data availability. If adequate, relevant data is available, the quantitative risk assessment is preferred since it provides an excellent means of assessing the risk, and hence, the alternative remediation methods. Conversely, where little, or no relevant failure data is available the analysis of choice has to be qualitative. Both methods are acceptable. The key is the use of a method that will provide a means of assessing if remediation is needed, and correlating the remediation method with the risk reduction attainable by the remediation.

d. Most often the analysis has little relevant data available and should use a qualitative risk assessment. One pseudo-quantitative risk assessment methodology that has been published is one that provides a quantitative index for each category and probability of the mishap and for each category of severity. The combined assessment, then, is one which allows the discernment of levels of risk into categories that are consistent across site assessments.

e. If one examines the probability and severity parameters relating to a "risk model" it is seen that the number of parameters is somewhat high, and the interrelationships that characterize the model are not easily established. Table D provides a very preliminary tabulation of some of the probability and severity parameters that are appropriate for a risk assessment. All of the probability parameters relate to the likelihood of initiating the energetic material. All of the severity parameters relate to characterizing the output of the energy material, or to the vulnerability of buildings and inhabitants to the output. Clearly, not all possible parameters are included since many parameters relate to the site specific geometry.

Conduct of Risk Assessment (RA).

The procedural flow for the conduct of a risk assessment has the elements shown in Figure 1.

(1) Develop threat list and threat distribution. As part of the problem definition the threats and threat distributions about the site are approximated. These data form the basis of defining the severity and the probability for the risk assessment.

(2) Develop probability of public encountering OEW. Past history is a reasonable indicator of the public encountering a threat during any traverse of the site. If the threat produces a damage zone that extends off of the site, more of the public could encounter the threat output.

Table D
PROBABILITY AND SEVERITY PARAMETERS FOR A RISK ASSESSMENT

PROBABILITY MODEL PARAMETERS

TYPE OF EXPLOSIVE

- Primary
- Secondary
- Insensitive
- Confinement Effects

TYPE OF PROPELLANT

- Double Base
- Single Base
- Configuration Effects
- Confinement Effects

INTEGRITY OF ORDNANCE ITEMS

WEATHER

- Dry / Cold
- Moist / Warm

FUSE SENSITIVITY

DEPTH OF BURIAL

- Surface
- "Critical Depth"
- Below "Critical Depth"

SAFE SEPARATION

- Cased Effects
- Enclosure Effects
- Explosive Sensitivity
- Explosive Weight Effects

PYROTECHNIC MATERIAL

- Type Of Material
- Confinement Effects
- Configuration Effects
- Initiation Energy

SEVERITY MODEL PARAMETERS

TNT EQUIVALENCY (EXPLOSIVE WEIGHT)

- Blast Pressure
- Blast Impulse

FRAGMENTATION

- Casing Material
- C/M
- TNT Equivalency

SITE CHARACTERISTICS

- Quantity-Distance
- Types Of Structures
- Types Of Inhabitants
- Fragment Barriers
- Traffic Characteristics

THERMAL RADIATION

- Energetic Mass Or Pool Size
- Stefan-Boltzman Constant
- Flame Temperature

(3) Develop severity profile for each threat. Severity profiles for the energetic output of each threat are produced by the threat characteristics. For explosive materials blast and fragments, primary and secondary, need to be considered. Pyrotechnic materials produce incendiary effects as well as potentially blast and fragment effects. Chemicals, in many forms, could produce toxic effects that are carried by the wind, or by the water, into contact with people, animals, or plants.

(4) Develop a RAC profile for each threat. The risk for each threat will, most likely, be different. Threats with recommended acceptability criteria less than 4 will need additional evaluation, and will be included as site threats. At some sites several threat types are extant at the same location. For instance, a firing range impact area could have been used for direct-fire weapons and indirect-fire rockets. A composite RAC profile can be made for the threat types, or the worst case threat can be used.

(5) Develop a RAC for the site. The site RAC provides a characteristic indicator of the hazard related to the site. If several areas of the site are evaluated the RAC may reflect a composite or a worst case, whichever is more appropriate. The site could also be subdivided into areas and a RAC developed for each area.

(6) Develop alternative remediation strategy. Each threat, and/or each site area, that has a RAC less than 4 will need a remediation strategy.

(7) Develop RAC for each remediation strategy. This provides an indicator of the risk reduction available through each remediation alternative.

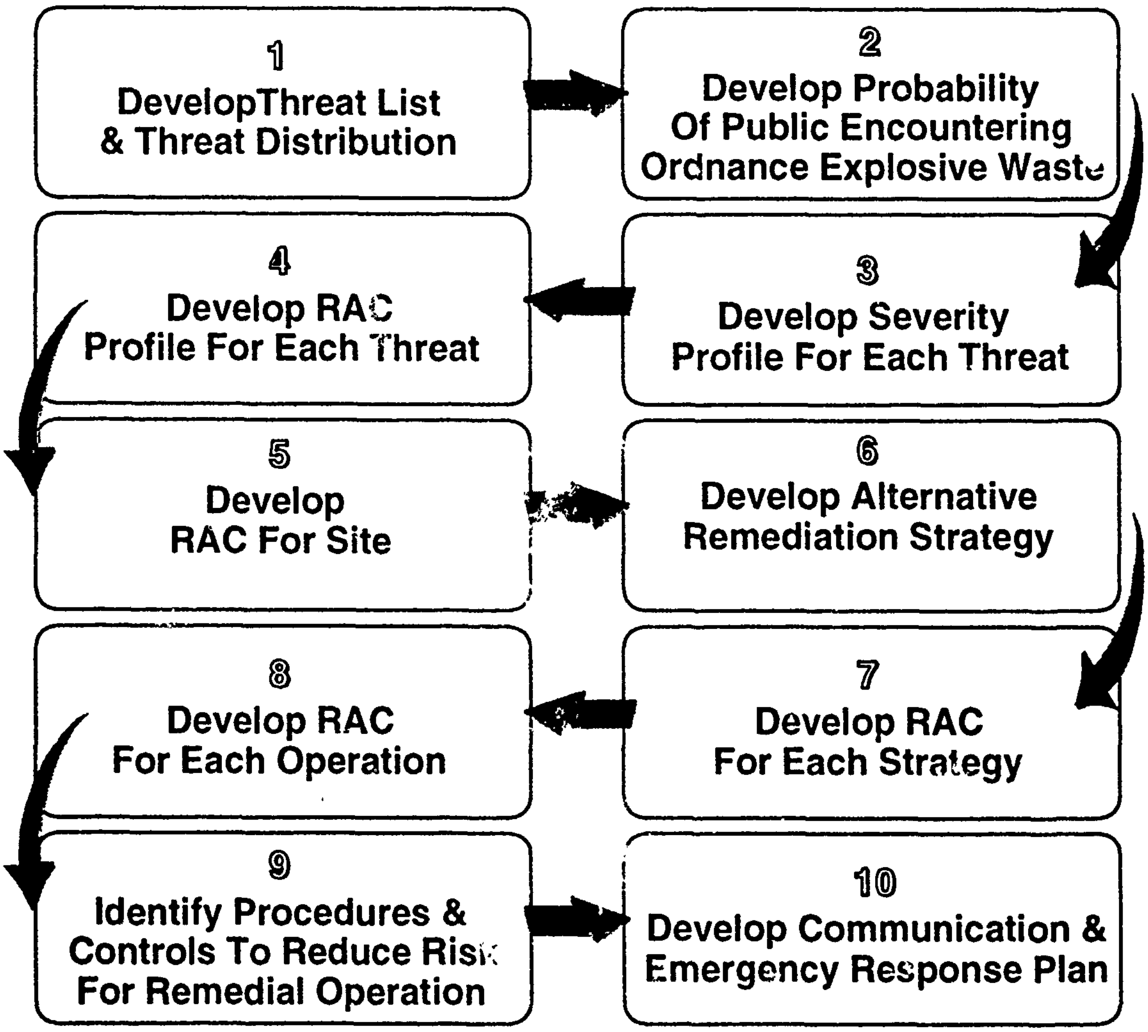
(8) Develop RAC for each remediation operation. Site remediation is not without its hazards. An assessment of the remediation operational risks is appropriate so that risks can be identified and controlled.

(9) Identify procedures and controls to reduce risk to RAC 3 or higher for each remedial operation.

(10) Develop communication and emergency response plan. This plan provides a standing operating procedure for control of remedial operations that are hazardous and responding to mishaps in a manner that minimizes the severity of casualties.

FIGURE 1

RISK ASSESSMENT PROCEDURAL FLOW



METHODS OF RISK REDUCTION

Reduce Probability.

Since risk has three components, probability, severity, and exposure, a reduction in any of the components produces a commensurate reduction in the risk. A reduction in the probability of a mishap can be effected by:

a. Removal of the threat. Clearly this is the most effective, and most likely the most costly, option. It does provide the most environmentally acceptable option and one which is most acceptable to the public.

b. Imposition of a barrier that is not an attractive nuisance, e.g., not a fence, moat, or covering. This is a restrictive option that can only be considered if the barrier is viable control and if the surface and subsurface water is not threatened by the OEW.

c. Imposition of warnings, e.g., signs, sensors with warning signals. The cost-benefit trade of this option if not usually viable. It can, however, be used in remote areas where the encounter probability between the threat and the population is very low.

d. Imposition of surveillance. This entails the use of sensors, monitors, and warning signals. As with (c) this option has limited application as a remedial action. However, it is viable as a temporary measure shortly before, or during, the conduct of remedial action.

e. Public education. This is a two edged sword. The public should be educated on the site, its threats to their well-being, and the remedial actions that are being taken. It is not a remediation option in itself, but it can reduce the risk of being coupled with an effective remediation option. If the public disagrees with the findings and the implementation of the remediation, public pressure is virtually assured to increase the remediation level.

Reduce Severity.

Reduction of the severity can be accomplished in several ways, all of which reduce the level of the threat, place a barrier between the threat and the population at risk, or increase the separation between the threat and the population at risk. The level of the threat can be reduced by:

(1) Removing the threats. This option also reduces the probability of encountering a threat.

(2) Partial removal of the dominant threats. For instance, surface threats, large threats, and the most lethal threats can be removed, leaving deeply buried and small OEW threats that produce low levels of severity.

(3) Neutralize. Chemical or biological neutralization are options to neutralize the threat in place. The threat can also be neutralized by incineration or, if appropriate, by detonation.

(4) Barrier. Placing a protective structure between the exposed population and the threat is one option of reducing the severity. Placing distance between is another option. Such an option may be achievable through zoning restrictions.

Reduce Exposure.

Reduction of exposure provides a reduction in the probability of an encounter with the threat. The main options in reducing the exposure include reducing the frequency of encounter by re-routing away from the threat radius of influence, or by restricting traffic to a pre-determined daily flow. Exposure reduction is not typically a viable risk reduction option.

SELECTION OF THE REMEDIATION METHOD

Alternatives.

a. The recommended acceptability criteria (RAC) provides the basis of establishing the need for remedial action. A RAC of 3 or lower indicates that some kind of remedial action is needed. A decision is then needed to establish whether the remediation method selected is to be a short term, or a permanent solution. Short term solutions are acceptable only if they are closely followed by permanent solutions. A short term solution reduces the immediate risk enough to secure the danger to the population. The long term solution provides a permanent risk reduction.

b. In selecting the remediation alternative it is initially desirable to delineate and rank each alternative solely on technical merit. After the technical ranking is achieved each alternative can be costed and ranked. Typically the cost ranking is not coincident with the technical ranking. Judgment, such as a weighted scale, is then needed to provide an additional basis for selecting the "best" remedial method.

Mandated Alternatives.

One problem with a risk assessment that produces a dollar value of the risk is that the value of a life, or a group of lives, is difficult to quantify in a manner that is universally satisfactory. One judgment that is used is to select the

remediation action that removes the threat when imminent or demonstrated threat to life or environment is indicated. Another typical mandated alternative is to select a remediation method that complies with a Federal, State, or local regulation. The "cost" of non-compliance is typically greater than the cost to comply.

Application of Advanced Technology.

a. There is a rapidly developing civilian market for remediation of hazardous waste sites. Advanced technology is being developed to make such remediation efforts more effective and efficient. Detection technology is being developed to allow detection and identification of chemicals without intimate contact between the detector and the chemical. Air quality compliance, however, is not yet certifiable on a real-time basis.

b. Biodegradation of exposed energetic materials and chemicals has a growing potential. Current technology uses extant bioagents for the degradation process. Genetic engineering is a potential technology that can be used to develop agents that biodegrade materials which are hazardous to clean up.

c. The use of on-site "portable" incinerators is becoming more common as site clearances are mandated in the civilian sector of the market. Mobile infrared incineration systems can provide destruction removal efficiency (DRE) factors of 99.9999% for the destruction of PCBs, with the ability to process up to 165 tons of waste per day.

Community Relations.

Community relations often have a strong influence in the determination of the remediation method selected, and its extent. There is a growing tendency for special interest groups, that are not a part of the community, to influence the sensitivity of the community to a perceived level of risk that far exceeds the actual risk. A community relation plan provides the mechanism of establishing, and considering, the community's attitudes toward the site remediation effort. Of particular importance is assurance that the community's interests are considered in all assessments, decisions, and actions. If changes to the remedial action plan are needed those changes should be disseminated to the community leaders.

Selection Rationale.

The cost-risk relation is the foundation for a remediation selection rationale. In actuality it is a cost-remediation alternative relation. The procedure is straight forward: (1) cost each alternative; (2) grossly quantify the risk

reduction to each remediation alternative; and (3) develop a cost-risk reduction curve. Needed is the predetermined risk criteria that should have been developed at the start of the risk assessment. Based on this criteria, select the remediation alternative that just meets the required level of risk reduction. The cost-risk reduction curve is typically a series of step functions, rather than a smooth curve. Before one remediation method is selected as the sole method, examine the data to see if a lower cost alternative is possible through the selection of more than one remediation method. The residual risk is seen to decrease as each risk reduction option is implemented. At the same time, there is a commensurate increase in cost that is not proportional to the decrease in risk reduction.

Other Potential Alternatives.

The ever increasing cost of remediation will eventually force the government to consider other alternatives for remediation. It is believed that these alternatives will serve to relieve the initial extensive remediation cost either through some sort of escrow funding or through cost sharing with property owners.

Escrow Funding.

Escrow funding is a principle where by the eminent hazard (i.e., surface/near surface) would be remediated and residual risks would be remediated as the potential for public exposure increased. Implementation would be to set aside an amount of money in an escrow fund. When the need would arise to address an OEW hazard, for example, due to utility construction, sufficient funds would be available to provide adequate OEW clearance without the long term project work cycle that now transpires.

Property Value Enhancement.

Much of the property excessed by the government was done at a significantly reduced price to offset the decreased value of the property due to OEW contamination. This was acceptable at the time due to the original intended land use of the property. As the land use needs have changed, property owners are now requesting remediation projects on these properties. Such remediation will enhance the value of the property then resulting in the potential of significant personal financial gain from this government effort. This author is proposing for consideration, a concept whereby the property owner would share in any property value enhancement of their property. The concept is in an early discussion stage with many legal considerations; however, it is a concept worthy of consideration.

SUMMARY

The Huntsville Division has been designated as the U.S. Army Corps of Engineers Mandatory Center of Expertise (MCX) and Design Center for Explosive Ordnance Engineering for the Army. With this designation, the Huntsville Division has demonstrated an element of technical capability and experience that is necessary to evaluate and remediate sites contaminated with EXO.

This paper has discussed the history of the DERP-FUDS for unexploded ordnance and the development of the RAC procedure for EXO contamination. In addition, this paper has presented the preliminary methodology development now being considered by USAEDH for project risk assessment and remediation alternatives.

The EXO is a safety and environmental hazard that has resulted in unreasonable risks to the general public, contractors, and Army personnel. It is felt that Army RAC procedures provide our environmental program managers with the necessary tools to evaluate public risks and make the appropriate decision concerning remediation of EXO contaminated sites. The program manager for EXO at the Huntsville Division is Mr. Robert Wilcox at 205-955-5802. The technical manager is Mr. C. David Douthat at 205-955-5785. The mailing address is U.S. Army Corps of Engineers, Huntsville Division, P.O. Box 1600, ATTN: CEHND-ED-SY/David Douthat or ATTN: CEHND-PM/Rob Wilcox, Huntsville, AL 35807-4301.

Operation Desert Sweep
The Restoration of Kuwait

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Abstract: This paper will provide the reader an insight into the magnitude of Ordnance and Explosive Waste (OEW) that is present in the US sector of Kuwait and how it is being detected, detonated or rendered safe, and disposed. Techniques and technologies that are being employed to ensure maximum safety and quality will be highlighted throughout this paper.

Operation Desert Sweep
The Restoration of Kuwait

In August 1990, Iraq invaded Kuwait. Then, as the United Nations coalition forces massed along the Saudi border in what was called Operation Desert Shield, Iraq dug in, laid mines and stockpiled hugh caches of munitions. When efforts to negotiate a peaceful settlement failed, Desert Storm was unleashed. For days, the Iraqi positions were bombarded in the most prolific aerial campaign in history. Then the land battle was joined, and in 100 hours Kuwait was free. The war was over, but a lethal battleground remained.

The Gulf War freed left the Kuwait countryside with enormous environmental restoration problems. Cashes of munitions, shells and other ordnance were left throughout the country. Oil wells were burning uncontrolled. Leaking oil created lakes of tar in the desert. The country's infrastructure was severely damaged - as road networks, utilities, housing, entire cities were destroyed. Damaged military hardware was scattered across the country, still filled with ordnance and POL (petroleum, oil and lubricants). Bunkers littered with all types of ordnance were dug throughout Kuwait. Hundreds of kilometers of minefields had been laid across the country, some covered by shifting sand and leaking oil.

When the Gulf conflict ended, the Kuwait Government divided the country (about the size of New Jersey) into six sectors and began negotiating Explosive Ordnance Disposal (EOD) contracts with six different counties, rewarding some of the coalition partners that helped oust Iraq. Later a seventh sector for Turkey was added.

The US designated sector is reportedly the heaviest contaminated area of the seven sectors, partly because it was subjected to the most intense aerial attacks of the war. American B-52s alone dropped over 800 tons of munitions during 527 interdiction missions against the Iraqi forces. Thousands of these munitions were cluster bombs which had a very high dud rate. In addition, unexploded ordnance (UXO) from more than a dozen countries is spread over the land.

The US sector also includes three major oil fields - Al Wafra, Um Gudair, and Al Burgan. In addition, there is a military airbase (Al Jaber) which was heavily targeted during the war, and over 150 km of minefields which were laid across the landscape. Finally, there are heavy contamination sites from unexploded ordnance in the central and southwestern areas.

In April 1991, CMS began negotiations with the Kuwait Ministry of Defense (KMOD). In October 1991, CMS was awarded a $134 million contract. The contract was divided into two phases: A four month mobilization phase provided time for build up of equipment, personnel and housing. An eighteen month performance phase covers the execution of the work, which includes: 1. Locating and clearing unexploded ordnance, 2. Removing war damaged military vehicles, and 3. Demolishing bunkers and reclaiming the land.

During the mobilization phase, CMS undertook a massive international effort to rebuild an infrastructure for use in country - living quarters, medical services, transportation, telephone, FAXes, copy machines, computers, etc. Experienced, trained and certified personnel were positioned to staff the more than 500-man team. The movement of $24 million worth of equipment from several countries, including Austria, US, and Germany, was a huge logistical challenge. Obtaining permits and other licensing requirements from the Kuwait MOD was complicated by the disarray of the country after the war. Despite all these road blocks, CMS successfully mobilized the personnel, equipment and materials within the required 4 month period.

One of the first tasks accomplished in Kuwait was the establishment of a support base of operations. CMS secured the Al Habdan Towers located along the coastline of Kuwait in the city of Fahaheel. This bombed-out multitower facility was completely renovated and refurnished. The facility houses all the American technicians working in Kuwait, and has office space for the CMS Program Office as well. The facility also has a large dining facility, recreation room, pool, tennis courts, and laundry facilities. Adjacent to the Towers is the CMS Motor Pool and maintenance facility.

The CMS EOD project, dubbed "Operation Desert Sweep", is staffed in Fahaheel, Kuwait and CMS headquarters in Tampa, Florida. The majority of CMS employees are former U.S. military personnel and are therefore comfortable with large scale EOD operations. As an example, the Deputy Director of Explosive Ordnance Disposal Operations is the former commandant of the EOD training school at Indian Head, Maryland.

After successful mobilization, CMS entered into the performance phase of the contract. The first step in the performance phase was to specify the requirements for the remediation operations. CMS divided the US sector into 36 smaller, more manageable subsectors. A thorough and detailed survey and reconnaissance was conducted on each subsector to identify the type, location and condition of UXO, mines, vehicles, trenches and bunkers.

During the survey and reconnaissance phase, EOD teams went into each subsector and gathered essential information on the contaminates found. The teams used Global Positioning Systems (GPS) to precisely record the position of ordnance and other contaminations. A CMS proprietary software system called Minefield and Ordnance Recovery System (MORS) was used to collate the data collected during the reconnaissance. Through the use of MORS, the data is archived and can be used to create very accurate maps showing the location of the items. The data in MORS, when combined with information such as vehicle and personnel availability, is used to plan, manage and conduct clearance operations. The MORS data is also essential in performing Quality Assurance for clearance operations.

Following proven military practices and procedures, CMS then disposes of ordnance, removes damaged equipment and restores the Kuwait desert to normalcy. Throughout the entire performance phase, CMS' own Quality Assurance Teams ensures the operations are being conducted safely and that clearance was accomplished to predetermined levels.

One of the major tasks facing the CMS EOD teams is the removal and disposal of approximately 150 kilometers of minefields containing over 750,000 anti-personnel and anti-tank mines from twenty different countries. The clearing of mines and ordnance is very dangerous; therefore, safety if foremost in all clearance operations. For example, the latest and most advanced Austrian Schiebel mine detector is in use. This device is capable of

detecting mines with very little metal content. New techniques are also evaluated, such as an ingenious mine cruncher. Where technology has not caught up to a particular requirement, innovative techniques are used to safely and successfully accomplish a clearance task.

One of the innovative techniques used in the disposal of anti-personnel mines is the use of a specially adapted excavator. The excavator has been armored and the bucket has been replaced with a specially designed rake which is used to detonate the smaller anti-personnel mines. After a tract is cleared, the CMS QA team certifies that the area is clean and safe.

In addition to the minefields, the Iraqis left seven immense underground ammo supply sites containing thousands of tons of Iraqi ordnance which must be removed. Furthermore, there were heavily fortified bunkers and trenches, which were used for ordnance storage, vehicle fighting positions and command posts. These bunkers must be reclaimed.

More than a dozen countries took part in the air and ground war. Therefore, it is difficult to imagine the variety of shells, rounds, grenades etc that litter the country side. For the most part, this ordnance is rendered safe and transported to a location in a remote area. The munitions are placed in a ditch; C4 blocks are placed around the UXO; covered with dirt and then imploded. Ordnance which can not be safely moved is destroyed in place. The munitions found in containers in the ASPs is turned over to the KMOD. The CMS QA team then inspects the area for cleared munitions.

The war damaged military equipment posses a difficult removal problem. The vehicle's ammunition stores and POL are still on board and must be removed first. Some of this equipment is buried in sand or standing in oil. After the vehicle is rendered safe, it is transported using heavy equipment and flatbed trucks to a holding area for later disposal by the KMOD. The CMS QA team and KMOD inspects the area for contaminates.

Professionalism and safety permeate the CMS operations. CMS personnel working on this project are all highly skilled professionals with emphasis on EOD disposal. All CMS EOD technicians are graduates of the US Naval EOD School in Indian Head, Maryland. They

have has extensive service in a US military EOD unit with hands-on experience and demonstrated leadership skills. Although already trained in EOD techniques, all EOD personnel are recertified through our training program. The CMS certification program is an eighty hour program combining classroom teaching with field exercises. No technicians are sent into the desert without adequate training and safety indoctrination.

CMS has established a Test and Evaluation group to continuously research new and innovative technologies, such as robotics, and remote sensing devices which can be applied to clearance operations. CMS also assists the Kuwait Government with public awareness programs. Finally, all CMS personnel are educated on Kuwait customs and culture before they enter the country.

To give the reader an idea of the enormous task that CMS has undertaken, the following program status, as of 26 JULY 1992 (5 months into the performance phase of the contract), is provided:

Tons of Ordnance Destroyed: 4,326
Tons of Ordnance Removed: 1,504
Mines Destroyed: 131,754
Vehicles Removed: 1,406
Sectors Cleared and QA'd: 12 (KMOD), 17 (CMS)

In summary, Operation Desert Sweep is an unprecedented EOD and site restoration program. CMS has successfully met the challenge and is not only meeting the requirements but is performing ahead of schedule. CMS is proud to participate with the government of Kuwait in this humanitarian operation.

ORDNANCE REMOVAL AND THE PUBLIC: PUBLIC AFFAIRS AT FORMERLY USED DEFENSE SITES

by Ken Crawford
Chief, Public Affairs
Huntsville Division, US Army Corps of Engineers

Presented at the 25th Department of Defense
Explosives Safety Seminar, August 1992

People don't like bombs in their backyards.

Dangerous unexploded ordnance exists on private property, sometimes in great quantities. Former ordnance plants, depots, arsenals and training areas, long abandoned by the Defense Department, now house industrial parks, wildlife preserves and subdivisions. Huntsville Division, U.S. Army Corps of Engineers, is tasked to remove ordnance and explosive waste from formerly used Defense sites as part of the Defense Environmental Restoration Program.

During ordnance removal operations, we keep the public informed. We do this for three reasons:

-- the government has an obligation to keep the public informed about its ongoing missions;

-- people fear unexploded ordnance; harbor misconceptions about it; or don't understand safety precautions;

-- adverse publicity or negative political attention can stop an ordnance removal effort.

The Right to Know

Although it's a trite expression and often misused, the public DOES have a "right to know." And the Defense Department is obligated to provide information with minimum delay. A document known as "Department of Defense Information Principles," signed by the Secretary of Defense in 1983, states: "It is the policy of the Department of Defense to make available timely and accurate information so that the public, Congress and members representing the press, radio and television may assess and understand the facts about national security and defense strategy.... Information will be made fully and readily available...."

Added to our obligation to inform the public, we try to keep them safe from unexploded ordnance. Bombs, projectiles and grenades were made, after all, to kill people. We try to impart safety information when we publicize our projects.

Bombs Are Scary

Because they have a right to know, the public demands information about our projects. They are alarmed about the danger to themselves and, especially, their children. If a grenade in the woods is bad, an artillery round near a school is a disaster waiting to happen. The possibility of chemical warfare agent is a nightmare.

Though the public generally understands that ordnance is dangerous, they have misconceptions about it and the military's role in removing it. Some of these misconceptions are:

-- old ordnance makes a nice souvenir;

-- ordnance can somehow hurt you even if you leave it alone;

-- "duds" didn't explode when they were fired, so they won't ever explode;

-- chemical warfare agent exists beneath the soil as a gas that, if released, can kill thousands;

-- the military never returned uncleared land to the public domain;

-- DERP actions come under the Environmental Protection Agency;

-- organizations which currently own former DoD sites are somehow financially or legally liable for the ordnance and its removal;

-- DoD is performing a "cover-up;"

-- the military is cooperating with local politicians for nefarious reasons.

The Show Must Go On

The third reason we keep the public informed is important to us. The public, through its elected leaders, can shut a project down. Although their nature is to ensure public safety, ordnance removal actions are not immune to criticism. Fear feeds on itself to panic the population. Some environmentalists perceive that we intend to damage the environment. Special interest groups attack our projects to enhance their own agendas. And politicians work to keep their constituents happy, even if it means demanding changes to a "perfectly good" removal plan.

Informing the Public

Like other environmental programs, ordnance removal falls under various laws -- CERCLA, SARA, NCP and DERP. All make provision for public participation. Huntsville Division keeps the public informed by holding public meetings, interacting with local officials and providing information to the media.

Combat Community Relations

Because of unexploded ordnance's danger to the public, removal actions often are quickly planned and quickly executed. At Huntsville Division, we've developed a process we like to call "Combat Community Relations." This involves gearing up rapidly to hold a public meeting the day before a project starts. When we have a more-detailed project with longer lead time, we may have several public meetings before we begin work.

Public meetings come in a variety of styles. Some are planned for large groups in a metropolitan setting. Others are small "public opportunities" for local residents at remote sites. Whatever the presentation style, all include:

-- briefings by project managers, ordnance removal contractors and other key individuals;

-- opportunity for public comments and questions;

-- offering of printed material, including fact sheets and maps.

The Division also establishes a local repository for information about the project. This is usually at a local library or other accessible site.

The Mayor Wants to Know

Local officials represent the people who elected them. As such, they have a desire to know about the project. In fact, they have a right to know about the project. We have found that, if we brief officials early and keep them informed, they tend to support our efforts. They also have been a great help in providing information about the local community and even in getting equipment or facilities.

Conversely, officials who were not contacted before we made public announcement tended to resent our neglect. They asked many pointed and embarrassing questions and were reluctant to support the program.

In our ordnance removal projects, we try to determine the local political structure and contact the appropriate leaders. Sometimes that contact is through a phone call or personal visit. At the very least, we try to send them a news release before we provide it to the media. We invite them to our public meetings and listen when they talk.

Reporters Can Help ... Really

Those connected with the military often view the press as the enemy. Well, some of them are. But normally not the reporters we work with. That's because our projects are generally at remote sites

where we work with local reporters. National reporters can invade a city, dig for dirt and alienate sources. A local reporter has to live in the town and work with sources long after the story has been written. They're generally fair and open minded. This doesn't mean a local reporter won't write a negative story -- it means he or she generally won't attack you unless you deserve it.

More important, reporters provide the best way to reach the public. One story can reach more people instantly than we could reach in a month. We have found that media coverage usually does not alarm local residents. Quite the opposite, it often calms them. A story aired on television casts our workers as experts and makes the process seem more routine to the viewers. It quickly becomes "old news" which does not upset the community.

Before we begin work at a site, we send local reporters two documents. The first is a news release, which describes the project, the contamination and the removal project. The second is what we call a "media alert." It alerts the reporter that we plan a "media day" concurrent with the start of the project. The media alert gives the reporter information about where and when to visit the site, what type of camera to bring and whom he or she can question.

We hold media days for two major reasons: they are a good vehicle to provide information and "visuals" to the reporter and they gather all the reporters together at a time and place of our choosing. The second factor keeps reporters from constantly interrupting work, while providing them with the opportunity they seek.

Our basic premise in setting up media days is that we have nothing to hide. Our only concerns are that we provide accurate information and that we keep the reporters safe. When the reporters arrive on site, they are given a safety briefing and are escorted by Public Affairs personnel. They can watch any action, talk to any government or contractor personnel, ask any questions and photograph any operation. Generally, they cannot photograph detonations, but that is because of the safety distances required. At one remote site with open fields, we were able to let reporters photograph detonations.

Throughout the project, we in Huntsville Division or the local Corps of Engineers District continue to update the media and answer questions.

Conclusion

In ordnance removal projects, Huntsville Division keeps the public informed. Through long experience, we have found that providing constant and accurate information to the public helps us to better serve that public.

OVERVIEW AND R&D TEST PLANNING FOR THE JOINT U.S./ROK R&D AND TEST PROGRAM FOR NEW UNDERGROUND AMMUNITION STORAGE TECHNOLOGIES

Gary Abrisz, Director, U.S. Army Technical Center for Explosives Safety

NARRATIVE

COVER - 1

GOOD MORNING. I AM GARY W. ABRISZ THE ASSOCIATE DIRECTOR OF THE U.S. ARMY TECHNICAL CENTER FOR EXPLOSIVES SAFETY IN SAVANNA, ILLINOIS. I AM ALSO THE U.S. PROGRAM MANAGER FOR THE JOINT U.S./REPUBLIC OF KOREA RESEARCH, DEVELOPMENT, AND TEST PROGRAM TO DEVELOP NEW UNDERGROUND AMMUNITION STORAGE TECHNOLOGIES.

I WILL PRESENT TO YOU TODAY A BRIEF OVERVIEW OF THE PROGRAM AND THE ON-GOING AND PLANNED TEST ACTIVITIES. I WILL BE GLAD TO ANSWER YOUR QUESTIONS AT THE CONCLUSION OF THIS PRESENTATION. SHOULD YOU HAVE SPECIFIC QUESTIONS ON THE TEST PLANNING, WE WILL PRESENT THEM TO MR. KIM DAVIS THE U.S. TECHNICAL PROGRAM MANAGER. HE WILL BE GLAD TO ANSWER THOSE.

DR. SONG AND DR. LEE FROM THE REPUBLIC OF KOREA AGENCY FOR DEFENSE DEVELOPMENT ARE ATTENDING THIS SEMINAR AND I WILL BE GLAD TO REFER QUESTIONS YOU MAY HAVE RELATIVE TO THEIR ACTIVITIES TO THEM.

- **PROGRAM MANAGERS**

ROK COLONEL JIN, SOO-JUN
EXPLOSIVES SAFETY MANAGEMENT BOARD, MND

U.S. MR. GARY W. ABRISZ
U.S. ARMY TECHNICAL CENTER
FOR EXPLOSIVES SAFETY

- **TECHNICAL MANAGERS**

ROK DR. SONG, SO-YOUNG
AGENCY FOR DEFENSE DEVELOPMENT

U.S. MR. L. KIM DAVIS
U.S. ARMY ENGINEER WATERWAYS
EXPERIMENT STATION

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VUGRAPH 2

THE PROGRAM MANAGERS AND TECHNICAL PROGRAM MANAGERS ARE SHOWN ON THIS CHART. I WILL SHOW YOU A CHART LATER RELATING TO ALL THE PROGRAM'S RESPONSIBLE ORGANIZATIONS.

MY KOREAN COUNTERPART IS REPUBLIC OF KOREA ARMY COLONEL JIN, SOO-JUN. MR. L. KIM DAVIS, U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, IS THE U.S. PROGRAM'S TECHNICAL MANAGER. HIS KOREAN COUNTERPART IS DR. SONG, SO-YOUNG THE AGENCY FOR DEFENSE DEVELOPMENT IN TAEJON, KOREA.

PRESENTATION OUTLINE

- INTRODUCTION
- GOAL/OBJECTIVE
- ISSUE
- BACKGROUND
- RESPONSIBLE ORGANIZATIONS
- PLAN
- EXPECTED RESULTS
- CONCLUSION

3

VUGRAPH 3

THIS IS THE OUTLINE FOR MY PRESENTATION.

GOAL

- IDENTIFY, TEST, EVALUATE, AND DEMONSTRATE NEW UNDERGROUND AMMUNITION STORAGE DESIGN CONCEPTS

OBJECTIVE

- DESIGN TO REDUCE OR CONTROL EXTERNAL BLAST AND DEBRIS EFFECTS FROM AN ACCIDENTAL EXPLOSION UNDERGROUND

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VUGRAPH 4

THE PROGRAM GOAL AND MAIN OBJECTIVE ARE STATED HERE. THE PROGRAM IS ESTABLISHED TO END WITH APPROVED NEW DESIGN CONCEPTS FOR APPLICATION WITHIN THE REPUBLIC OF KOREA WHICH SHOULD HAVE APPLICATIONS WORLDWIDE.

OVER THE LAST DECADE, A NUMBER OF EXPLOSIVE TESTS HAVE BEEN CONDUCTED TO INVESTIGATE THE HAZARDOUS EFFECTS THAT MAY BE PRODUCED BY ACCIDENTAL EXPLOSIONS IN UNDERGROUND MAGAZINES. THESE EFFECTS INCLUDE AIRBLAST, DEBRIS THROW, GROUND SHOCK, AND THE PROPAGATION OF AN EXPLOSION TO ADJACENT STORES OF AMMUNITION. THE TESTS PROVIDE EXPERIMENTAL DATA REQUIRED TO REFINE THE CURRENT DEPARTMENT OF DEFENSE (OR NORTH ATLANTIC TREATY ORGANIZATION) SAFETY STANDARDS, AND/OR TO EVALUATE NEW DESIGN FEATURES FOR UNDERGROUND MAGAZINES.

NEW CONCEPTS FOR UNDERGROUND MAGAZINES ARE PRESENTLY BEING EVALUATED, EITHER TO PROVIDE NEW STORAGE CAPABILITIES, OR TO DRASTICALLY REDUCE THE PRESENT HAZARD RANGES FOR UNDERGROUND AMMUNITION STORAGE. IN SPITE OF THE TREMENDOUS ADVANCES IN OUR ABILITY TO MATHEMATICALLY SIMULATE THE COMPLEXITIES OF MAGAZINE EXPLOSIONS USING COMPUTER MODELS, SMALL-SCALE EXPLOSIVE TESTS CONTINUE TO BE AN INVALUABLE SOURCE OF DATA AND INSIGHTS. THE JOINT U.S./REPUBLIC OF KOREA RESEARCH AND DEVELOPMENT PROGRAM FOR NEW UNDERGROUND AMMUNITION STORAGE TECHNOLOGIES, TO BE CONDUCTED OVER THE NEXT 5 YEARS, WILL

VUGRAPH 4 (CONT)

INVOLVE EXTENSIVE SMALL-SCALE AND INTERMEDIATE-SCALE TESTING TO INVESTIGATE, EVALUATE, AND DOWN-SELECT PROMISING DESIGN FEATURES THAT SHOULD ENABLE US TO GREATLY REDUCE THE EXTERNAL HAZARDS FROM AN UNDERGROUND MAGAZINE. OUR DIRECT EMPHASIS HAS BEEN ON OUR STORAGE IN THE REPUBLIC OF KOREA.

ISSUE

- U.S./ROK AGREEMENTS REQUIRE APPLICATION OF THE U.S. DOD AMMUNITION AND EXPLOSIVES SAFETY STANDARDS

- SERIOUS QUANTITY DISTANCE (QD) VIOLATIONS EXIST IN ROK

- PERMIT A REALISTIC USE OF U.S./ROK TECHNICAL CAPABILITIES TO REDUCE QD REQUIREMENTS IN THE ROK AND THE U.S.

ISSUE NARRATIVE

VUGRAPH 5

THE ISSUE THE DEPARTMENT OF DEFENSE WAS FACING IN KOREA IN THE MID 1980s AND CONTINUES TO RECOGNIZE, IS WHAT HAS GENERATED THIS OFFICE OF THE SECRETARY OF DEFENSE-DIRECTED AND ARMY MANAGED PROGRAM. THE STORAGE OF U.S. DEPARTMENT OF DEFENSE AMMUNITION IN KOREA RELATES TO APPLICATION OF U.S. EXPLOSIVES SAFETY STANDARDS.

THE SITUATION IS CURRENTLY THAT THE STANDARDS CAN NOT BE ACCOMMODATED TO THE FULL EXTENT AND MANY VIOLATIONS AND EXPOSURES RESULT.

THIS RESEARCH AND DEVELOPMENT EFFORT AS STATED IS TO DETERMINE THE USE OF NEW TECHNICAL APPLICATIONS TO REDUCE QUANTITY DISTANCE REQUIREMENTS.

THE MEMORANDUM OF AGREEMENT AND THE ASSOCIATED STATEMENT OF WORK ARE DIRECTED TOWARD THIS ISSUE. THEY ARE INTENDED TO DESIGN CONCEPTS TO ELIMINATE THE EXISTING SERIOUS EXPLOSIVES SAFETY VIOLATIONS IN THE REPUBLIC OF KOREA AS WELL AS THROUGHOUT THE DEPARTMENT OF DEFENSE STORAGE COMPLEX.

ESSENCE OF THE ISSUE

- TRADE-OFFS BETWEEN:
  - <u>SAFETY</u> - BUFFER ZONES TO COMPLY WITH SAFETY STANDARDS
  - <u>OPERATIONAL CAPABILITY</u> - AMMUNITION TO MEET ARMY/NAVY/USAF MISSIONS
  - <u>COST INVESTMENT</u> - LAND FOR BUFFER ZONES ($10,000 TO $100,000 PER ACRE)

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VUGRAPH 6

DISCUSSING THE ISSUE IN KOREA IN MORE DETAIL RELATES TO MANY SITUATIONS AT THE AMMUNITION STORAGE SITES WHICH FORCE US TO MAKE TRADE-OFFS BETWEEN SAFETY, OPERATIONAL REQUIREMENTS, AND COST INVESTMENT.

THE DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY STANDARDS REQUIRE QUANTITY DISTANCE ZONES OR BUFFER ZONES TO PROTECT AREAS EXTERNAL TO OUR SITES AS YOU ARE AWARE. MANY TIMES IN AREAS SUCH AS KOREA, OUR MISSION REQUIRES QUANTITIES OF AMMUNITION WHICH VIOLATE THE STANDARDS.

THE COST OF REAL ESTATE IN HIGHLY POPULATED REGIONS FOR USE AS THE REQUIRED BUFFER ZONES BECOMES PROHIBITIVE. THEREFORE, THE NEED TO REDUCE THE ZONES AND SATISFY SAFE STORAGE BECOMES PARAMOUNT.

<u>ESSENCE OF THE ISSUE</u>

EXAMPLE:

CONSIDER \$50,000/ACRE. - A TYPICAL EARTH-COVERED MAGAZINE REQUIRES:

710 ACRES FOR 250,000 lbs (EXPLOSIVE WEIGHT) = 35.5 M FOR LAND ALONE

SAFETY *<u>VS</u>* *OPERATIONAL CAPABILITY* *<u>VS</u>* ***COST INVESTMENT***

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ESSENCE OF THE ISSUE NARRATIVE

VUGRAPH 7

THIS IS AN EXAMPLE TO CONSIDER.

AT $50K AVERAGE PER ACRE A TYPICAL STORAGE SITUATION RELATING TO AN ABOVEGROUND EARTH-COVERED MAGAZINE WOULD REQUIRE $35.5M OF INVESTMENT TO PURCHASE REAL ESTATE REQUIRED WITHIN THE QUANTITY DISTANCES BUFFER ZONE. THIS IS IF ONE CAN CONSIDER THE REAL ESTATE IS AVAILABLE FOR PURCHASE. IN MANY INSTANCES IN KOREA ACQUISITION IS IMPROBABLE AT BEST.

BACKGROUND

SEP 1987 - DDESB EXPLOSIVES SAFETY SURVEY IDENTIFIED VIOLATIONS AND CONCERNS

AUG 1988 - U.S. DOD AND ROK MND ESTABLISHED A JOINT TECHNICAL WORKING GROUP

MAR 1989 - SEVEN PROPOSED STORAGE CONCEPTS WERE EVALUATED

VUGRAPH 8

WITH THAT AS THE ISSUE, I WOULD LIKE TO NOW QUICKLY COVER THE BACKGROUND RELATIVE TO THE PROGRAM DEVELOPMENT. BEGINNING IN THE 1985 AND 1987 TIME PERIOD WHEN THE VIOLATIONS IN KOREA WERE FIRST DOCUMENTED BY THE DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD, OUR DEPARTMENT OF DEFENSE AND REPUBLIC OF KOREA MINISTRY OF NATIONAL DEFENSE DIRECTED ESTABLISHMENT OF A TECHNICAL WORKING GROUP TO RESOLVE THE ISSUE.

SEVERAL PROPOSALS WERE GENERATED AND WERE EVALUATED BY THE GROUP MADE UP OF REPRESENTATIVES OF DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD, U.S. ARMY, U.S. NAVY, U.S. AIR FORCE, AND REPUBLIC OF KOREA MINISTRY OF NATIONAL DEFENSE.

THE UNDERGROUND STORAGE CONCEPT PRESENTED BY WATERWAYS EXPERIMENT STATION AT THAT TIME WAS SELECTED AMONG THE VARIOUS SERVICE CONCEPTS PRESENTED. THE MOUNTAINOUS TERRAIN AND GRANITE ROCK GEOLOGY IN KOREA ADAPTS WELL TO THIS UNDERGROUND CONCEPT.

BACKGROUND

JUL 1989 - U.S./ROK STATEMENT OF INTENT

FEB 1990 - UNDERGROUND STORAGE CONCEPT SELECTED

MAR 1990 - A JOINT R&D PLAN RESULTED IN A DRAFT MOA

VUGRAPH 9

THE U.S./REPUBLIC OF KOREA SIGNED A STATEMENT OF INTENT TO ENTER INTO AN AGREEMENT IN JULY 1989.

A DRAFT MEMORANDUM OF AGREEMENT WAS DEVELOPED IN MARCH OF 1990.

BACKGROUND

APR 1990 - CANDIDATE FOR NUNN AMENDMENT COOPERATIVE R&D PROGRAM FUNDS

MAY 1990 - DRAFT MOA TO HQDA AND OSD FOR STAFFING

- PROJECT IDENTIFIED FOR HQDA FUNDING FY 94 AND FY 95

NOV 1990 - CERTIFIED BY OUSD(A) (NUNN $)

VUGRAPH 10

IN 1990 ALSO, HEADQUARTERS, DEPARTMENT OF THE ARMY IDENTIFIED PROGRAM FUNDING FOR OUTYEARS. THE PROGRAM WAS CERTIFIED BY OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR ACQUISITION AS AN APPROVED CANDIDATE FOR THE U.S. CONGRESSIONAL NUNN AMENDMENT COOPERATIVE RESEARCH AND DEVELOPMENT PROGRAM FUNDING IN NOVEMBER OF THAT YEAR. A TOTAL OF $9.5M WAS PROGRAMMED. THE REPUBLIC OF KOREA HAS PROGRAMMED $3.5M FOR THEIR EFFORT.

BACKGROUND

JAN 1991 - OUSD(A) AUTHORITY TO NEGOTIATE AND CONCLUDE MOA

APR 1991 - MOA NEGOTIATIONS AND AGREEMENT

JUL-AUG 1991 - MOA SIGNED

AUG 1991 - NUNN FUNDS RELEASE - R&D COMMENCES

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VUGRAPH 11

A WHOLE SERIES OF NEGOTIATIONS TOOK PLACE AND A MEMORANDUM OF AGREEMENT AND STATEMENT OF WORK RESULTED IN AN AGREEMENT IN 1991. THE FUNDING WAS PROVIDED AND OUR RESEARCH AND DEVELOPMENT EFFORTS GOT UNDERWAY.

RESPONSIBLE ORGANIZATIONS

	U.S.	ROK
PROPONENT:	CG, COMBINED FORCES COMMAND AND U.S. FORCES, KOREA (USFK)	MINISTRY OF NATIONAL DEFENSE (MND)
DIRECTING OFFICE:	OFFICE OF THE UNDER SECRETARY OF DEFENSE (ACQUISITION)	MND DIRECTOR, LOGISTICS BUREAU
REGULATORY AGENCY:	DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD	MND EXPLOSIVES SAFETY MANAGEMENT BOARD
PROGRAM MGMT:	U.S. ARMY TECHNICAL CENTER FOR EXPLOSIVES SAFETY	MND EXPLOSIVES SAFETY MANAGEMENT BOARD
R&D LEAD LAB:	USACE WATERWAYS EXPERIMENT STATION	AGENCY FOR DEFENSE DEVELOPMENT (ADD)

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RESPONSIBLE ORGANIZATIONS

VUGRAPH 12

I MENTIONED EARLIER I WOULD SHOW THE RESPONSIBLE ORGANIZATIONS.

THIS EFFORT WAS DRIVEN BY THE 20TH SECURITY CONSULTATIVE MEETING AT OUR SECRETARY OF DEFENSE LEVEL AND THE REPUBLIC OF KOREA MINISTRY OF NATIONAL DEFENSE LEVEL. WE ENJOY A HIGH VISIBILITY AND EQUAL SUPPORT.

WE EXPECT THE PROGRAM TO RESULT IN NEW CRITERIA FOR UNDERGROUND AMMUNITION STORAGE WHICH WILL BE REVIEWED AND APPROVED BY THE U.S. DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD AND THE REPUBLIC OF KOREA MINISTRY OF NATIONAL DEFENSE EXPLOSIVES SAFETY MANAGEMENT BOARD AS THE REGULATORY AGENCIES SHOWN HERE. BOTH ORGANIZATIONS ARE DIRECTLY INVOLVED IN THE RESEARCH AND DEVELOPMENT AND TEST PROCESSES AND EVALUATIONS AS WE PROCEED.

U.S. TECHNICAL ADVISORY GROUP (TAG)

PURPOSE: ADVISE THE PROGRAM MANAGERS (PMs) AND TECHNICAL MANAGERS ON THE NEW UNDERGROUND AMMUNITION STORAGE TECHNOLOGIES (UAST) PROGRAM ACTIVITIES AND CONCEPTS

U.S. MEETINGS -	NOV 91	WES	VICKSBURG, MS
	JUN 92	WES	VICKSBURG, MS
ROK MEETING -	MAY 92	TAEJON, KOREA	

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U.S. TECHNICAL ADVISORY GROUP

VUGRAPH 13

BOTH THE U.S. AND REPUBLIC OF KOREA HAVE ESTABLISHED TECHNICAL ADVISORY GROUPS. WE AGREED TO DO THIS IN OUR MEMORANDUM OF AGREEMENT NEGOTIATIONS. THIS CHART SHOWS OUR TECHNICAL ADVISORY GROUP PURPOSE AND PAST MEETINGS. A CHARTER HAS BEEN DEVELOPED AND INCORPORATED INTO THE PROGRAM DOCUMENTS.

THE U.S. HAS HAD TWO MEETINGS AND THE REPUBLIC OF KOREA HAS HAD ONE. REPUBLIC OF KOREA REPRESENTATIVES ATTENDED THE FIRST U.S. MEETING AT WATERWAYS EXPERIMENT STATION AND U.S. REPRESENTATIVES ATTENDED THE FIRST REPUBLIC OF KOREA MEETING AT THE AGENCY FOR DEFENSE DEVELOPMENT IN TAEJON, REPUBLIC OF KOREA THIS YEAR. OUR NEXT U.S. MEETING IS SCHEDULED FOR THE FIRST WEEK OF DECEMBER 1992 AT SOCORRO, NEW MEXICO.

U.S. TAG MEMBERSHIP

ORGANIZATION	NAME
DDESB SECRETARIAT	DR. CHESTER E. CANADA
USAF:	
AFSA	MR. PAUL D. PRICE, P.E.
U.S. ARMY:	
CEHND	MR. PAUL LAHOUD
BRL	MR. ONA R. LYMAN
AMC DCS AMMO	MR. ROBERT J. FAHY
U.S. NAVY:	
NSWC	MR. MICHAEL M. SWISDAK
NCEL	MR. JAMES E. TANCRETO
KOREA:	
U.S., USFK J4	COLONEL TOMMERVIK

VUGRAPH 14

YOU SEE MANY FAMILIAR NAMES ON THIS CHART.

THIS MEMBERSHIP REPRESENTS MUCH OF THE EXPLOSION EFFECTS EXPERTISE WITHIN THE U.S. DEPARTMENT OF DEFENSE. THE U.S. ARMY MATERIEL COMMAND DEPUTY CHIEF OF STAFF FOR AMMUNITION AND U.S. FORCES, KOREA, J4, REPRESENT THE LOGISTICS INPUT AND THE USER REQUIREMENT CONSIDERATIONS IN THIS CONCEPT DEVELOPMENT. AS A MEMBER OF THE DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD SECRETARIAT, DR. CANADA PROVIDES THE CHAIRMANSHIP IN SUPPORT OF THE PROGRAM AND TECHNICAL MANAGERS.

THE REPUBLIC OF KOREA HAS AN EQUALLY QUALIFIED AND AN IMPRESSIVE GROUP OF EXPERTS TO REVIEW THEIR ACTIVITIES AND COORDINATE WITH THIS U.S. GROUP OF EXPERTS. WE HAVE BEEN VERY MUCH IMPRESSED BY THEIR ACTIVITIES AND RESULTS.

PLAN

- FIVE PHASES OF WORK, OVER FIVE-YEAR PERIOD:
  - CY 91 - PHASE 1: R&D PLANNING AND PREPARATION
  - CY 92 - PHASE 2: SMALL-SCALE TEST PROGRAM
  - CY 93 - PHASE 3: INTERMEDIATE-SCALE INVESTIGATIONS
  - CY 94 - PHASE 4: VALIDATION TESTS
  - CY 95 - PHASE 5: FINAL CONCEPT DESIGNS (AND PORTION OF CY 96)

15

NARRATIVE FOR PLAN

VUGRAPH 15

THIS CHART SIMPLY SHOWS THAT THE PROGRAM HAS BEEN PLANNED OUT OVER A FIVE PHASE PERIOD. THE STATEMENT OF WORK REFLECTS THIS. THE FACT THAT WE STARTED WITH FUNDING ORIGINALLY INTENDED FOR 1990 IN EARLY SEPTEMBER 1991, MEANS THAT THE FIVE PHASE PROGRAM WILL NOW EXTEND INTO 1996. THE ORGANIZATION OF THE PROGRAM RELATES TO THE INITIAL PLANNING AND PREPARATION THROUGH SMALL-SCALE TESTING INTO INTERMEDIATE TESTS AND THEN MUCH LARGER VALIDATION TESTS. THESE WILL PROBABLY OCCUR IN PLACES LIKE SOCORRO, NEW MEXICO AND CHINA LAKE, CALIFORNIA. ALL OF THE PHASES ARE FOR THE PURPOSE OF CULMINATING IN FINAL CONCEPT DESIGNS THAT CAN BE APPROVED BY BOTH THE REPUBLIC OF KOREA EXPLOSIVES SAFETY MANAGEMENT BOARD AND THE U.S. DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD. I WILL SPEAK IN GENERAL TO THE RESEARCH AND DEVELOPMENT PLANNING AND TESTING WITH THE FOLLOWING CHARTS.

PHASE 1. R&D PLANNING AND PREPARATION

- DESIGNATE TECHNICAL PROGRAM MANAGERS AND ORGANIZE RESEARCH TEAMS
- ESTABLISH TECHNICAL ADVISORY GROUP
- LITERATURE SEARCH
- IDENTIFY AND SELECT COMPUTER CODES FOR ANALYSIS OF MAGAZINE DESIGNS (E.G., SPIDS, SHARC, AB-HULL, BLASTIN)
- OBTAIN GAGES AND OTHER TEST EQUIPMENT
- IDENTIFY PROMISING TECHNIQUES FOR REDUCTION OF PRESSURE/IMPULSE FROM EXPLOSIONS IN UNDERGROUND MAGAZINES: DESIGN SMALL-SCALE TEST PROGRAM

16

VUGRAPH 16

PHASE 1 HAS BEEN COMPLETED ACCOMPLISHING THE ACTIONS ON THIS CHART. I HAVE MENTIONED THE PROGRAM MANAGERS AND THE U.S. AND REPUBLIC OF KOREA TECHNICAL PROGRAM MANAGERS WERE ESTABLISHED TO PLAN THIS COORDINATED REPUBLIC OF KOREA/U.S. RESEARCH AND DEVELOPMENT PROGRAM. THE LEAD LABS IN REPUBLIC OF KOREA (AGENCY FOR DEFENSE DEVELOPMENT) AND U.S. (WATERWAYS EXPERIMENT STATION) ARE RESPONSIBLE FOR ACCOMPLISHING THESE TECHNICAL ACTIVITIES.

WE RECRUITED MEMBERS FROM ORGANIZATIONS WITH EXPERTISE RELATED TO RESEARCH AND DEVELOPMENT OBJECTIVES, TO ADVISE ON RESEARCH AND DEVELOPMENT PROGRAM PROGRESS AS A TECHNICAL ADVISORY GROUP, AS I DISCUSSED PREVIOUSLY.

WE HAVE ASSEMBLED PERTINENT DOCUMENTS THROUGH A LITERATURE SEARCH. WE CONTINUE TO ANALYZE EXISTING RESEARCH AND DEVELOPMENT INFORMATION TO IDENTIFY PRESENT TECHNOLOGY FOR PREDICTION AND CONTROL OF EXPLOSION HAZARDS FOR UNDERGROUND MAGAZINES.

AREAS OF EMPHASIS IN THE SEARCH CATEGORIES HAVE BEEN:

- AIRBLAST PRESSURE/IMPULSE EFFECTS INTERNALLY, AT THE EXIT, AND EXTERNAL TO THE PORTAL.

VUGRAPH 16 (CONT)

- WE ARE CONSIDERING CHAMBER SEPARATION (WITH RESPECT TO SYMPATHETIC DETONATION FROM AIRBLAST, GROUND SHOCK, AND SPALLING OF ADJACENT WALL).

WE ARE LOOKING AT INFORMATION AND DATA ON:

- BUFFER/BAFFLED STORAGE SYSTEMS (TO REDUCE SYMPATHETIC DETONATIONS).
- GROUND SHOCK HAZARDS (FREE FIELD).
- EJECTA DEBRIS HAZARDS AND DEBRIS TRANSPORT MECHANICS (IN TUNNEL AND EXTERNAL).
- AND ALSO IDENTIFYING PERTINENT DATA FROM SHOCK TUBES AND LARGE GUN TESTS.

WATERWAYS EXPERIMENT STATION AND THE AGENCY FOR DEFENSE DEVELOPMENT CONTINUE TO:

- EVALUATE CODE CAPABILITIES AND LIMITATIONS.
- THEY HAVE TRAINED RESEARCH TEAMS IN USE OF SELECTED CODES.
- THEY ARE VERIFYING CODES AGAINST EXISTING EXPERIMENTAL DATA.
- WATERWAYS EXPERIMENT STATION HAS OBTAINED BLAST PRESSURE GAGES AND DATA RECORDING EQUIPMENT NEEDED FOR EXPLOSIVE TESTING (SMALL-SCALE) IN THE ON-GOING PHASE 2.
- THEY ARE EVALUATING DATA ON EFFECTS OF LOADING DENSITY (BASED ON CHAMBER VOLUME AND TOTAL VOLUME).

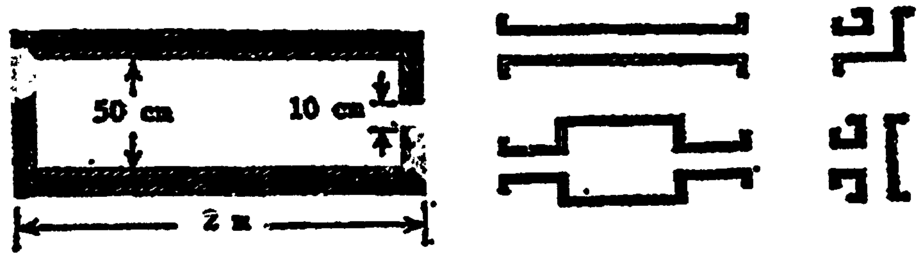
PHASE 2 SMALL-SCALE TEST PROGRAM

- CONSTRUCTION OF SMALL-SCALE TEST FACILITIES (U.S. AND ROK)
- CONDUCT SMALL-SCALE EXPLOSIVE TEST PROGRAM
- COMPUTER MODEL STUDIES OF CHAMBER/TUNNEL DESIGN PERFORMANCE
- EVALUATE RESULTS OF SMALL-SCALE TESTS AND COMPUTER MODEL STUDIES
- SELECT BEST DESIGN FEATURES FOR FURTHER STUDY

PHASE 2 NARRATIVE

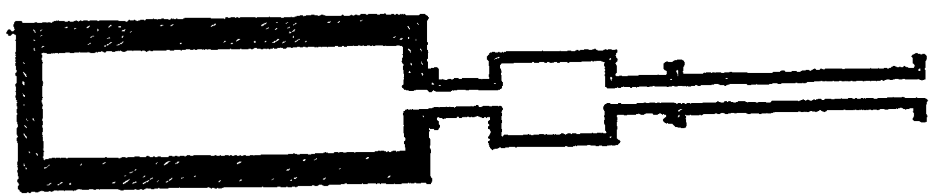
VUGRAPH 17

A SERIES OF SMALL-SCALE MODEL TESTS ARE BEING CONDUCTED BY WATERWAYS EXPERIMENT STATION AND THE AGENCY FOR DEFENSE DEVELOPMENT IN THE REPUBLIC OF KOREA.



a. Blast chamber and pipe (tunnel) components.

b. Assembly to investigate effect of tunnel lengths.



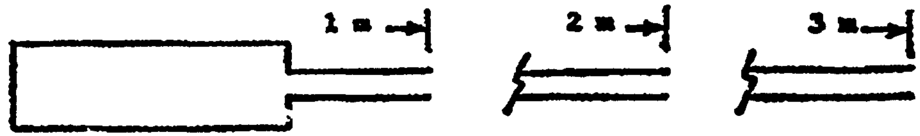
c. Assembly to investigate effect of an expansion chamber.

17A

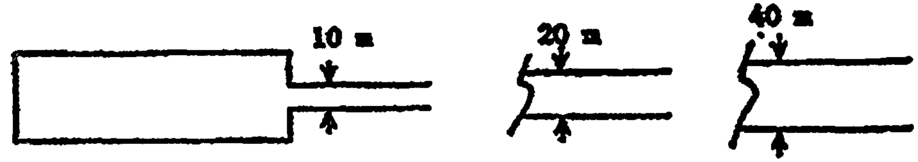
VUGRAPH 17A

WATERWAYS EXPERIMENT STATION IS USING A STEEL DETONATION CHAMBER FABRICATED IN THE WATERWAYS EXPERIMENT STATION SHOPS. THE U.S. CHAMBER IS 2 METERS LONG WITH AN INTERNAL DIAMETER OF 50 CM AND A WALL THICKNESS OF 15.25 CM. THE CHAMBER VOLUME IS 0.365 M^3 (12.885 $FEET^3$).

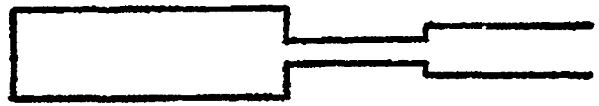
VARIOUS CONFIGURATIONS OF STEEL PIPE ARE ATTACHED TO THE DETONATION CHAMBER TO INVESTIGATE UNDERGROUND MAGAZINE DESIGN PARAMETERS.



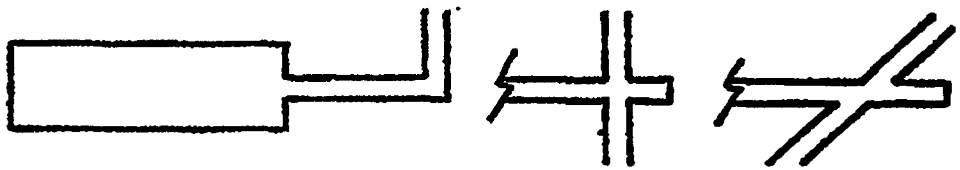
a. Effect of tunnel length.



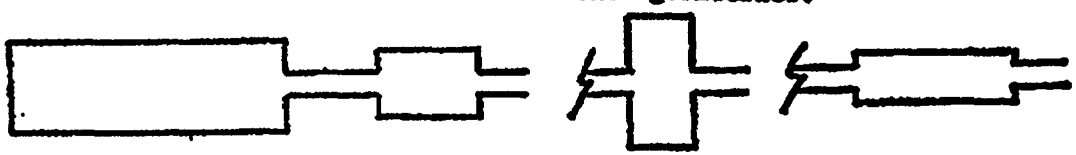
b. Effect of tunnel/chamber diameter ratios.



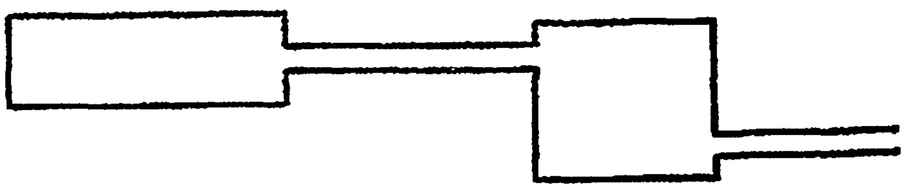
c. Effect of tunnel constrictions.



d. Effect of tunnel intersection geometries.



e. Effect of expansion chamber geometries.

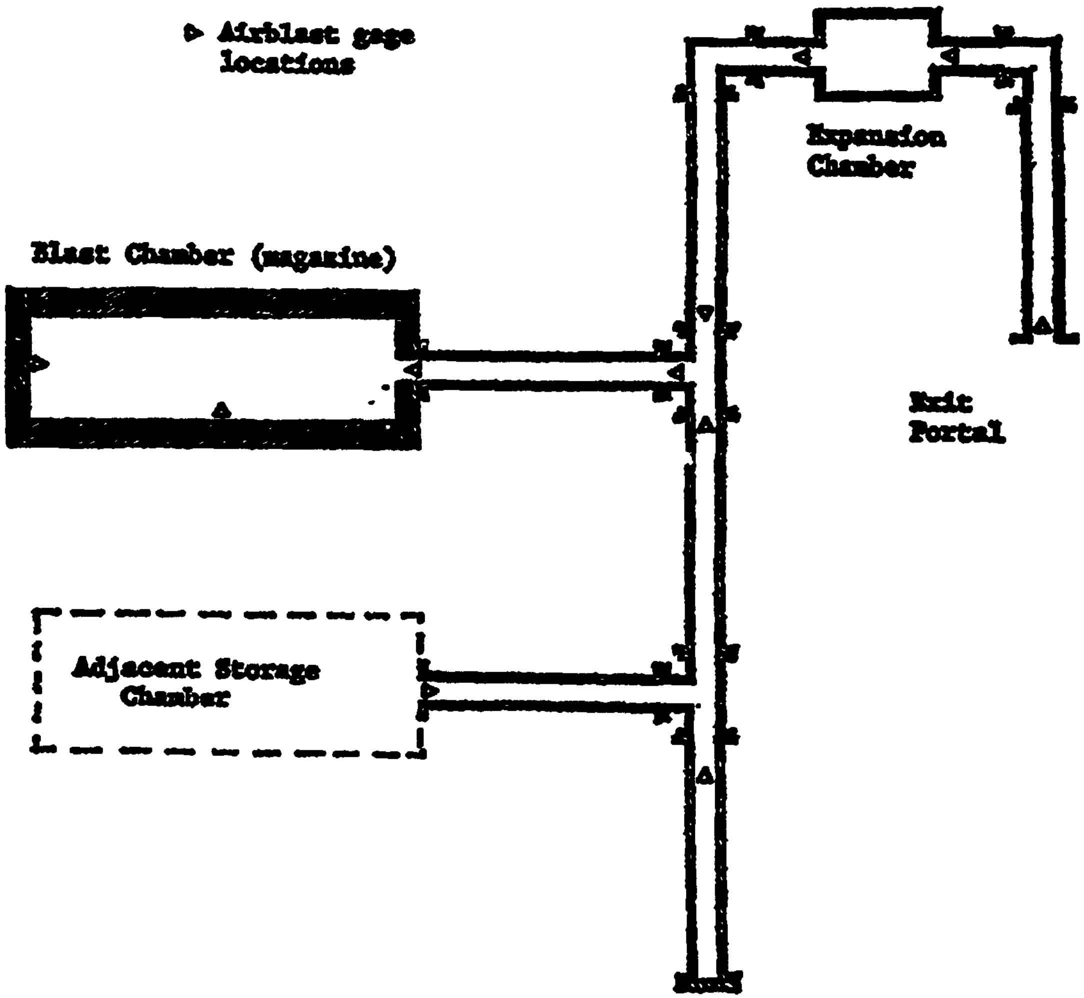


f. Effect of offset expansion chamber exits.

17B

VUGRAPH 17B

THE GENERIC MODEL TESTS WILL EVALUATE THE EFFECTS OF; (1) TUNNEL LENGTH, (2) TUNNEL/CHAMBER DIAMETER RATIO, (3) TUNNEL VOLUME, (4) TUNNEL CONSTRICTIONS, (5) TUNNEL INTERSECTION GEOMETRY, (6) EXPANSION CHAMBER GEOMETRY, (7) MULTIPLE TUNNEL EXITS,


Airblast gage locations
Blast Chamber (magazine)
Expansion Chamber
Exit Portal
Adjacent Storage Chamber

17C

VUGRAPH 17C

AND (8) COMPLEX TUNNEL LAYOUTS.

PHASE 2 SMALL-SCALE TEST PROGRAM

- CONSTRUCTION OF SMALL-SCALE TEST FACILITIES (U.S. AND ROK)
- CONDUCT SMALL-SCALE EXPLOSIVE TEST PROGRAM
- COMPUTER MODEL STUDIES OF CHAMBER/TUNNEL DESIGN PERFORMANCE
- EVALUATE RESULTS OF SMALL-SCALE TESTS AND COMPUTER MODEL STUDIES
- SELECT BEST DESIGN FEATURES FOR FURTHER STUDY

18

VUGRAPH 18

THE CHAMBER IS BEING INSTRUMENTED FOR GAS PRESSURE, TEMPERATURE, AND THERMAL FLUX. GAS PRESSURE MEASUREMENTS ARE MADE WITH GAGES MOUNTED AT THE OUTER END OF THREE HOLES DRILLED THROUGH THE SIDE WALL OF THE CHAMBER AT POINTS 45 CM FROM EACH END AND AT THE MID-LENGTH. THERMAL GAGES (A THERMAL FLUX GAGE AND THERMOCOUPLE) ARE MOUNTED IN THE REAR WALL OF THE CHAMBER.

ADDITIONALLY WE ARE LOOKING AT:

- THE EFFECTIVENESS OF DEBRIS TRAPS AND BARRICADES FOR DETONATION DEBRIS CONTAINMENT.
- ALSO OPERATION AND EFFECTIVENESS OF TUNNEL CLOSURE SYSTEMS NEAR TUNNEL EXITS (LOW PRESSURE REGION) WILL BE STUDIED.

IN THE REPUBLIC OF KOREA, THE AGENCY FOR DEFENSE DEVELOPMENT HAS CONSTRUCTED FACILITIES ALSO. THE TESTS BY BOTH THE WATERWAYS EXPERIMENT STATION AND AGENCY FOR DEFENSE DEVELOPMENT ARE PLANNED TO COMPLEMENT EACH OTHER IN VERIFYING RESULTS. THE REPUBLIC OF KOREA PROGRAM RELATES TO A SIMILAR CHAMBER AND PIPING APPLICATION.

FOR INTERMEDIATE-TO-HIGH LOADING DENSITIES (20 TO 100 KG/M^3) THE PLANS ARE TO EVALUATE:

VUGRAPH 18 (CONT)

- THE EFFECT OF CHAMBER LOADING DENSITY ON TUNNEL ENTRY PRESSURES.

- THE EFFECT OF RATIOS OF CHAMBER CROSS-SECTION TO TUNNEL CROSS-SECTION, AND CHAMBER VOLUME TO TUNNEL CROSS-SECTION, ON TUNNEL ENTRY PRESSURES.

- THE CONTRIBUTION OF GAS PRESSURE "JETTING" ON EXTERNAL BLAST PRESSURES FROM DETONATIONS AT HIGH LOADING DENSITIES.

- THE EFFECT OF STEEP TOPOGRAPHIES FOR CONTROLLING EXTERNAL BLAST EFFECTS.

- THE EFFECT OF CHAMBER SPACINGS (IN ROCK) ON DAMAGE TO "ACCEPTOR" CHAMBERS.

- THE EFFECTIVENESS OF "SELF-SEALING" CHAMBER DESIGNS AND BLAST-ACTIVATED CHAMBER PLUGS FOR CONTAINMENT OF BLAST PRESSURES IN THE HIGH-PRESSURE REGION.

COMPUTER MODEL STUDIES ARE ON-GOING IN THE U.S. AND REPUBLIC OF KOREA:

THIS INCLUDES IN THE U.S. THE:

- INVESTIGATION OF CHAMBER SELF-SEALING CONCEPTS WITH SHARC HYDROCODE.

- DETERMINING MINIMUM ROCK COVER DEPTHS OVER CHAMBERS FOR DETONATIONS OF DIFFERENT LOADING DENSITIES, FOR DIFFERENT ROCK PROPERTIES, USING SHARC AND UNIVERSAL DISCRETE ELEMENT CODE.

- DETERMINING DEBRIS EJECTION VELOCITIES FROM CHAMBERS AND ACCESS TUNNELS,

VUGRAPH 18 (CONT)

EVALUATING DEBRIS CONTROL WITH BLAST TRAPS (IN TUNNELS) AND EXTERNAL BARRICADES, USING SHARC AND UNIVERSAL DISCRETE ELEMENT CODE.

- ALSO DETERMINING DYNAMIC GAS FLOW PRESSURE HISTORIES FOR ACTIVATION OF TUNNEL CLOSURE SYSTEMS.

ALSO IN THE REPUBLIC OF KOREA THEY ARE:

- CALCULATING STRESS LOADS TRANSMITTED THROUGH ROCK TO "ACCEPTOR" CHAMBERS FROM "DONOR" CHAMBER DETONATIONS, AS FUNCTION OF ROCK TYPES AND CHAMBER SPACINGS.

- THEY ARE DETERMINING PRESSURE HISTORIES AS FUNCTION OF LOADING DENSITIES, TUNNEL LENGTHS, AND TUNNEL LAYOUT GEOMETRIES, USING HULL AND SHARC CODES.

- ALSO THEY ARE DETERMINING TUNNEL PRESSURE REDUCTIONS FROM EXPANSION CHAMBERS AND TUNNEL CONSTRICTIONS, USING HULL AND SHARC CODES.

PHASE 2 IN THE U.S. IS EXPECTED TO BE COMPLETED IN DECEMBER THIS YEAR. THE REPUBLIC OF KOREA EFFORT MAY CONTINUE A FEW MONTHS INTO 1993.

BASED ON THE EVALUATIONS BY EACH LEAD LAB (AGENCY FOR DEFENSE DEVELOPMENT AND WATERWAYS EXPERIMENT STATION) AND THE RECOMMENDATIONS OF THE TECHNICAL ADVISORY GROUPS THE U.S. AND REPUBLIC OF KOREA TECHNICAL PROGRAM MANAGERS

VUGRAPH 18 (CONT)

WILL IDENTIFY THE MOST PROMISING DESIGN FEATURES (OF THOSE INVESTIGATED IN PHASE 2) FOR FURTHER INVESTIGATION IN PHASE 3.

PHASE 3 INTERMEDIATE-SCALE TEST PROGRAM

- DESIGN WILL BE A DIRECT RESULT OF PHASE 2 TESTING PROGRAM

  - U.S. IS PLANNING TO USE EXISTING MINES WITH MODIFICATIONS IN NEW MEXICO

  - ROK HAS GEO-A ISLAND JUST OFF THE PENINSULA

19

NARRATIVE PHASE 3

VUGRAPH 19

THE TEST OBJECTIVES AND TEST PLANS FOR 1/5 AND 1/8-SCALE INTERMEDIATE EXPLOSIVE TESTS VARY FROM 10 KG TO 500 KG. FURTHER COMPUTER MODEL STUDIES WILL BE DEFINED FOR EACH SIDE'S CONTRIBUTION TO PHASE 3 OF THIS JOINT RESEARCH AND DEVELOPMENT PROGRAM.

U.S. INTERMEDIATE-SCALE TEST SITE. THE U.S. TECHNICAL MANAGER HAS LOCATED A SITE NEAR MAGDALENA (SOCORRO COUNTY), NEW MEXICO, THAT FULLY MEETS PLANNED TEST REQUIREMENTS. THE SITE IS A PRIVATELY-OWNED MINING COMPLEX, CONTAINING TWO TUNNELS, NAMED LINCHBURG AND PATTERSON MINES. THE TWO TUNNELS ARE SEPARATED BY A FEW HUNDRED METERS AND ARE JOINED AT THE REAR BY A [illegible]E, CAVERNOUS EXCAVATION. THE MINE IS CURRENTLY INACTIVE. THE TUNNELS ARE FAIRLY STRAIGHT, 2 METERS WIDE, 2 METERS HIGH, AND APPROXIMATELY 1,000 METERS LONG. THE GEOLOGY OF THE MINE COMPLEX INDICATES COMPETENT ROCK THROUGHOUT, ALLOWING THE EXCAVATION OF UNDERGROUND TEST CHAMBERS UP TO 5 METERS WIDE AND 3 METERS HIGH WITH A MINIMUM OF ROCK BOLTING OR OTHER REINFORCEMENT. THE TOPOGRAPHY IN THE VICINITY OF THE TUNNEL ENTRANCES, WITH A LARGE HILL ACROSS FROM A SMALL CANYON, WILL PROVIDE OPPORTUNITIES TO MEASURE EXTERNAL BLAST OVER MOUNTAINOUS TERRAIN. (THE U.S. HAS RECENTLY SECURED A ONE-YEAR LEASE ON THIS PROPERTY.)

VUGRAPH 19 (CONT)

REPUBLIC OF KOREA INTERMEDIATE-SCALE TEST SITE. THE REPUBLIC OF KOREA TECHNICAL MANAGER HAS SELECTED GEO-A ISLAND (PRONOUNCED GO-AAH), AN UNINHABITED ISLAND IN THE YELLOW SEA, APPROXIMATELY ONE HOUR OFF THE COAST, SOUTHWEST OF SEOUL. THE SITE IS ADJACENT TO ANHEUNG PROVING GROUND, AN AGENCY FOR DEFENSE DEVELOPMENT, ORDNANCE TESTING FACILITY. THE ISLAND WILL PROVIDE TWO SEPARATE TESTING LOCATIONS; ONE SITE CONSISTS OF A STEEP RIDGE INTO WHICH TEST CHAMBERS CAN BE BORED OR EXCAVATED; THE SECOND SITE WILL PROVIDE A MORE NATURAL TERRAIN AREA (HILLSIDE, CUL DE SAC), REPRESENTATIVE OF TYPICAL KOREA TOPOGRAPHY.

EXPECTED RESULTS

- SOLUTION TO AMMUNITION STORAGE SAFETY PROBLEM IN KOREA (UNDERGROUND STORAGE)
  - ALLOW CONFORMANCE WITH THE STANDARDS, REMOVING THOUSANDS OF U.S./ROK MILITARY AND CIVILIANS FROM RISK
- SOLUTION WILL ALSO PROVIDE BONUS BENEFITS:
  - APPLICABLE WORLDWIDE TO MANY U.S. ARMY NAVY, USAF SITES
    - MUCH GREATER SECURITY
    - MAJOR IMPROVEMENT IN SURVIVABILITY
    - ASSURED LONG-TERM COST SAVINGS

20

VUGRAPH 20

THIS PROGRAM WILL PROVIDE APPLICATIONS FAR BEYOND OUR AMMUNITION STORAGE IN KOREA. ALL OF OUR PAST STORAGE APPLICATIONS AND EXPLOSIVES TESTING CONDUCTED WITHIN THE DEPARTMENT OF DEFENSE, AND THE EUROPEAN COMMUNITY AS WELL, SUPPORTS THE EXPLOSION EFFECTS EXPERTS' CONSIDERATIONS THAT NEW UNDERGROUND STORAGE CONCEPT DESIGNS HAVE THE POTENTIAL TO SOLVE THE EXPLOSION PROBLEMS; AID IN BETTER SECURITY; PROVIDE FOR AMMUNITION SURVIVABILITY; AND RELATE TO COST SAVINGS BY REDUCING THE NEED FOR VALUABLE REAL ESTATE TO SATISFY SAFETY BUFFER ZONES, AS I MENTIONED IN THE BEGINNING. IT WILL ALSO REDUCE ASSOCIATED FACILITY COST INVESTMENT AND GAIN LONG-TERM SAVINGS

EXPECTED RESULTS
(CONTINUED)

- SIGNIFICANTLY INCREASE SECURITY (INTRUSION, THEFT, OR SABOTAGE) WITH REDUCED MANPOWER AND REDUCE ASSOCIATED FACILITY COST INVESTMENT.
- PROVIDE ALL-WEATHER LOADING/UNLOADING ENVIRONMENT AND INCREASED SHELF LIFE OF AMMUNITION
- REDUCE VISIBILITY OF MILITARY PRESENCE AND PROVIDE COMPLETE PROTECTION AGAINST ENEMY SURVEILLANCE

21

VUGRAPH 21

THE LAST ITEM ON THIS CHART RELATES TO THE REPUBLIC OF KOREA PLACING GREAT EMPHASIS ON SURVIVABILITY OF THE AMMUNITION STOCK AS WELL AS SECURITY AND THE REDUCED VISIBILITY OF THE ACTIVITIES IN THE SOUTH FROM AN ENEMY.

CONCLUSION

- JOINT ROK/U.S. R&D PROGRAM TO PROVIDE NEW DESIGN CONCEPTS IS WELL UNDERWAY
- PHASE 2, SMALL-SCALE TESTING IS ON-GOING
- PHASE 3, INTERMEDIATE-SCALE TESTING IS BEING PLANNED
- PROGRESS TO DATE HAS BEEN EXCELLENT AND IS EXPECTED TO CONTINUE.

22

VUGRAPH 22

IN CONCLUSION - THIS JOINT RESEARCH AND DEVELOPMENT EFFORT IS EXPECTED TO RESOLVE MANY OF THE QUESTIONABLE TECHNICAL AREAS SUCH AS EXPLOSION CONTAINMENT, DEBRIS THROW, BLAST OVERPRESSURE MEASUREMENT, AND PREDICTIONS AND GROUND SHOCK APPLICATIONS. THE PROGRAM IS WELL UNDERWAY. SEVERAL OF THE RELATED ACTIVITIES OF PHASE 2 ARE BEING PRESENTED AT THIS SEMINAR BY MESSRS. KIM DAVIS AND CHARLES JOACHIM, WATERWAYS EXPERIMENT STATION, AND DRS. LEE AND SONG OF THE REPUBLIC OF KOREA AGENCY FOR DEFENSE DEVELOPMENT.

PLANNING, AS I INDICATED, FOR THE INTERMEDIATE-SCALE TESTING IS ON-GOING. BOTH THE U.S. AND REPUBLIC OF KOREA TECHNICAL MANAGERS INTEND TO VISIT THE U.S. PROPOSED TESTING SITE IN NEW MEXICO FOLLOWING THIS SEMINAR.

WE ARE EXCITED ABOUT OUR JOINT EFFORTS AND FULLY EXPECT GOOD RESULTS WHICH CAN BE SHARED WITH THE ENTIRE EXPLOSIVES SAFETY COMMUNITY. THE SUCCESS OF OUR FIRST THREE TECHNICAL ADVISORY GROUP MEETINGS SUPPORTS OUR CONTENTION THAT WE ARE PROGRESSING WELL.

THANK YOU!

EFFECT OF BLAST TRAPS ON AIR-BLAST PROPAGATION IN UNDERGROUND EXPLOSIVE STORAGES

So-young Song, Jaimin Lee, Jae Woon Ahn, Hyung Won Kim, Jin Soo Choi

Agency for Defense Development
Taejon, Republic of Korea

ABSTRACT

A series of model tests were conducted with small-scale steel magazines to access the blast reduction effectiveness of elbow or dead-end spaces placed in front of the storage chambers of underground ammunition storage magazines. Pre-test hydrocode calculations were made with SHARC code and HULL code to know the accuracy of their predictions. Experimental values of peak-pressures were compared with the predictions of the DOD Standards.

1. INTRODUCTION

The ROK and the US are jointly developing new designs for underground ammunition storage facilities that will significantly reduce the hazard areas surrounding ammunition storage sites. One potential design concept is a multi-chamber facility equipped with hazard control features. Among the hazard control features that will be investigated are blast/debris traps, chamber/tunnel closing devices, explosion propagation barriers, and so on.

Although there can be various type of blast-traps in the multi-chambered underground ammunition storages, we investigated only the dead-end space and the elbow space placed in front of the storage chamber.[1] A series of model tests were conducted with small scale steel magazines to assess the blast reduction effectiveness of blast traps mentioned above. Pre-test hydrocode calculations have been made with SHARC code and HULL code to know the accuracy of their predictions and to understand the physics of accidental explosions in the underground ammunition storage facilities.

2. LAYOUTS OF SMALL-SCALE MODEL TESTS

The storage chamber of the small-scale model magazine was made of steel and its inside dimmension was L100xW50xH23cm^3. The top, bottom and rear wal s were made of 20.3cm thick steel plate and the rest of walls were made of 10.2cm thick steel plate. The total volume of this chamber was 0.115m^3. The explosive used in the test was 1.9kg of Composition C-4 and the chamber loading density was 16.7 kg/m^3. The access tunnel was made of steel pipes of 20cm inside diameter. The lengths of branch passageway and main passageway of the access tunnel were 50cm and 400cm respectively. The branch passageway and the main passageway were connected together by direct contact, an elbow, and a tee with dead-end trap to make a straight magazine, an elbow magazine, and a dead-end magazine, respectively, as shown in

Figures 1-3. Length of dead-end trap was varied as 20cm, 40cm and 60cm as shown in Figure 3.

Pressure-time histories of the blastwave travelling down the tunnel were monitored by both pre-test hydrocode calculations and experimental measurements at the locations shown in the Figures 1-3 with circular dots. Pressure-time histories of the blastwave in the free field outside of the magazine were recorded only by experimental measurements at locations shown in Figure 4.

3. PRE-TEST HYDROCODE CALCULATIONS

Propagation of blastwaves in the model magazines shown in Figures 1-3 were simulated two-dimensionally by using the HULL code and the SHARC code with walls treated as completely-reflecting boundaries. The pressure-time histories of blastwave from the SHARC code simulation and the HULL code simulation are shown in Figures 5-6 respectively : The explosive was 1.9kg of Composition C-4, and the pressure-time histories were obtained in the dead-end space of the 20cm-dead-end magazine.

Although the pressure-time histories from SHARC code simulation show qualitatively similar behavior to those from HULL code simulation, especially in the front part, the former have much higher peak-pressure than the latter have.

Results of pre-test hydrocode calculations are compared with those of experimental measurements in Chapter 5.

4. EXPERIMENTAL MEASUREMENTS

Pressure-time histories of blastwave travelling down the tunnel and in the free field were recorded by using piezo-electric transducers at locations shown by circular dots in the Figures 1-4. The instrumentation system consists basically of dual mode charge amplifiers (PCB 464A), a multi-channel digitizer (LeCroy 6810) and a personal computer.

Pressure-time history measured experimentally at the same location as that of

Figures 4-5, is shown in Figure 7. It can be seen that peak-pressure and waveform of the experiment is closer to those of the HULL code simulation than to those of the SHARC code simulation at the location in the dead-end space which is placed close to storage chamber.

Measured peak-pressures in the tunnel are shown in Figure 8 as a function of total volume.[2] When there was a dead-end space, peak-pressure was reduced in a great quantity around the dead-end space. The oscillatory behavior of pressure-total volume curve seems to be due to the reflection of blastwaves at the chamber walls or tunnel walls. The reflected waves move faster than and catch up the primary waves to become a single high amplitude waves. Straight magazine shows much higher peak-pressure than any other magazine at the tunnel exit.

Peak-pressure in the free field along the 0-degree line which is extension of the center line of the tunnel near the exit as shown in Figure 4, is shown in Figure 9 as a function of distance from exit. Peak-pressures of the straight magazine test have higher values than those of dead-end magazine test or elbow magazine test.

5. DISCUSSIONS

Hydrocode calculations of peak-pressures in the tunnels are compared with experiments in Figures 10-14 for straight magazine, elbow magazine, 20cm-dead-end magazine, 40cm-dead-end magazine and 60cm-dead-end magazine respectively. For straight magazine, SHARC code predicts the test data quite exactly in the far region of the tunnel. For elbow magazine, peak-pressure in the near region of the tunnel can be predicted very well by HULL code and test data in the far region of the tunnel are close to SHARC code prediction. For dead-end magazine, HULL code and SHARC code give lower bound and upper bound to the test data of peak-pressures respectively.

Experimental measurements of peak pressures in the tunnels are compared with the predictions of DOD Standards in Figure 8.[2] Peak pressures at locations near the tunnel exit were much higher for straight magazine and much lower for elbow magazine and dead-end magazines than the predictions of DOD Standards. Under-estimation of

DOD Standards for straight magazine seems to be due to rigidity of chamber walls, and over-estimations of DOD Standards for other magazines seem to be due to blast-trap effects.

Experimental measurements of peak-pressures in the free field outside of tunnels are compared with the predictions of DOD Standards in Figure 9. The DOD Standards over-estimate the experiments in the near field due to the effects of blast traps for elbow magazine and dead-end magazines. The predictions of DOD Standards approach the peak-pressures of experimental measurement in the far field. However measured pressures of straight magazine have higher values than those of any other magazine even in the far field.

6. CONCLUSIONS

We conducted a series of model tests with small scale steel magazines to assess the blast reduction effectiveness of elbow or dead-end spaces placed in front of the storage chambers of underground ammunition storage magazines. We also made pre-test hydrocode calculations with SHARC code and HULL code to know the accuracy of their predictions.

The conclusions are as follows :

1. Elbow or dead-end space placed in front of storage magazine lowered a large amount of pressure amplitude at the tunnel exit and a considerable amount of pressure amplitude at the far region in the free field.

2. SHARC code predicted the tunnel exit pressure quite exactly for straight magazine. In general, HULL code and SHARC code give lower bound and upper bound to the test data of peak-pressures respectively.

3. DOD Standards over-estimated the experimental peak-pressures near the exit of the tunnel for the elbow magazine and the dead-end magazines, and under-estimated them for the straight magazine. The experimental values of peak-pressures approached the estimations of DOD Standards in the far region of free field.

REFERENCES

1. "Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives", AC/258-D/258, January 1991, p. Ⅲ-54.
2. "DOD Explosive Safety Criteria for Underground Storage of Military Munitions", Revised Version for Section 9-G of DOD 6055.9-STD, Asst. Secretary of Defense, Washington, D.C., November 1990.

REMARK
* Explosive weight 1 9kg
* Unit of length cm
* Circular dots trasducer locations

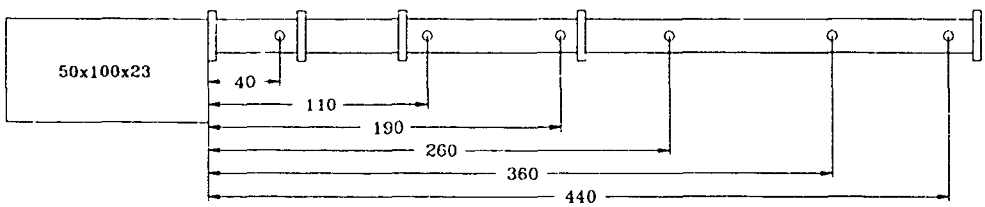


Figure 1 Straight Magazine

REMARK
* Explosive weight 1 9kg
* Unit of length cm
* Circular dots trasducer locations

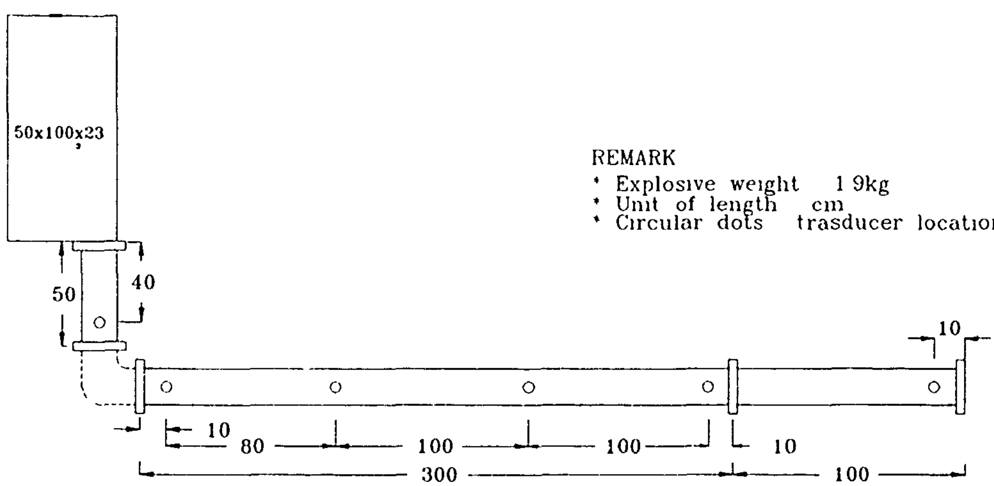


Figure 2 Elbow Magazine

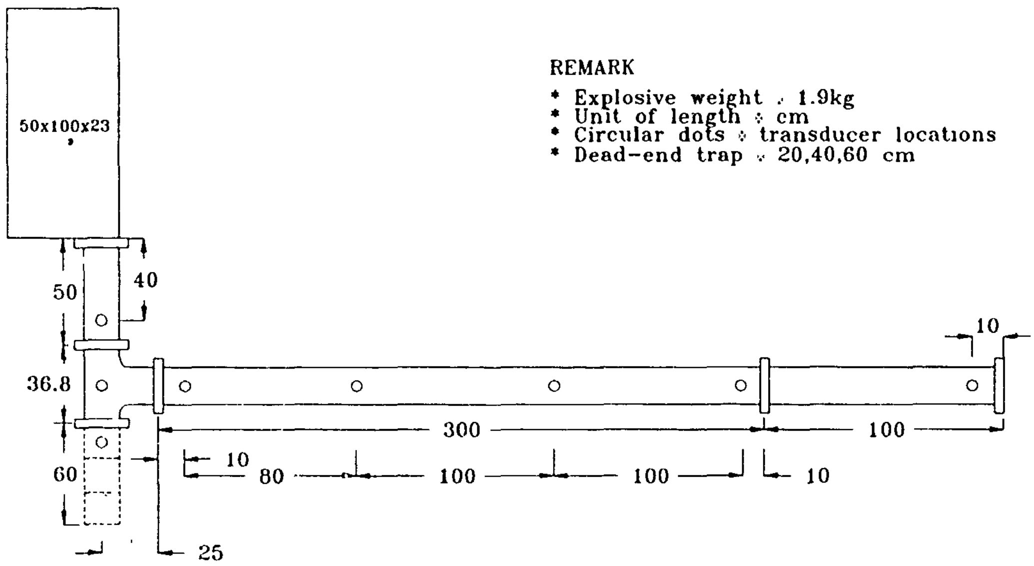


Figure 3. Dead-End Magazine.

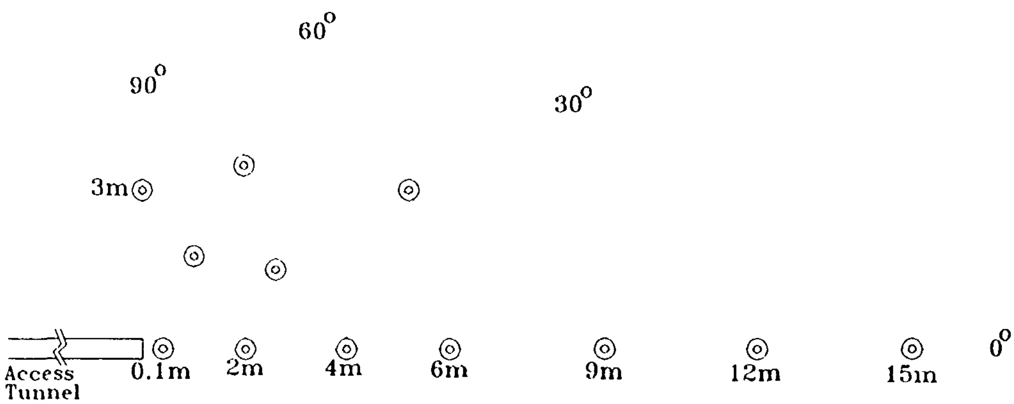


Figure 4. Transducer Locations in the Free Field.

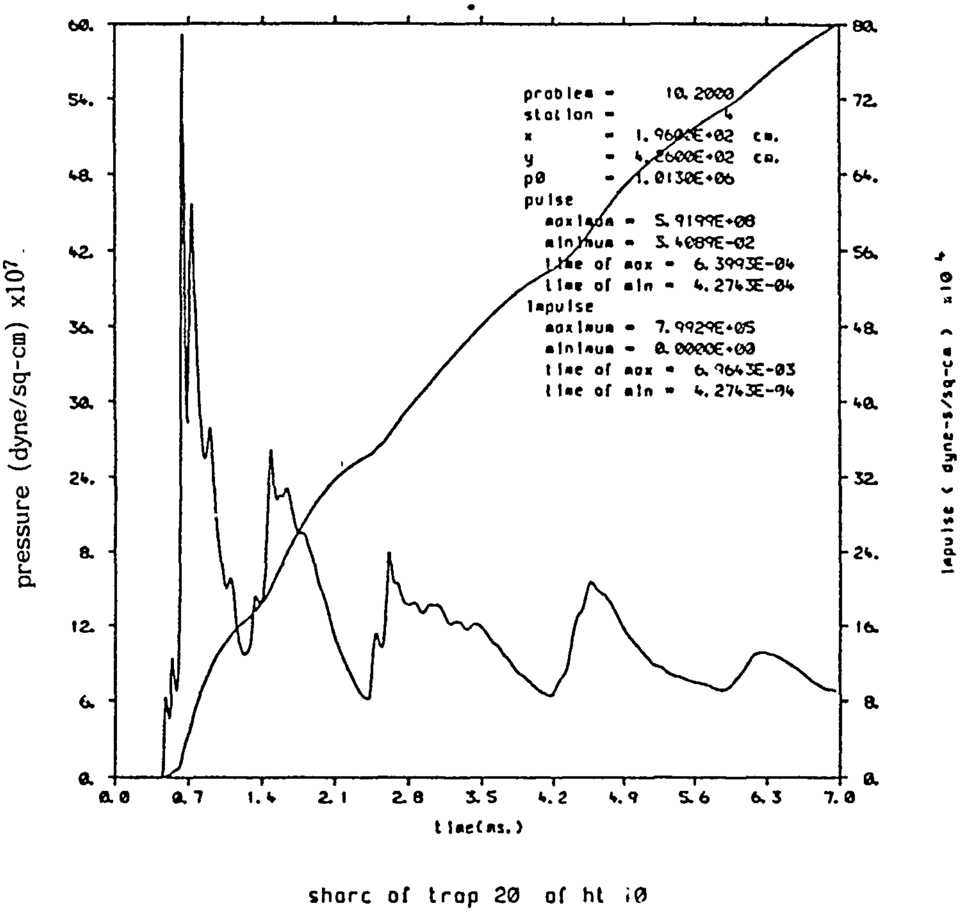


Figure 5. SHARC Code Simulation of Pressure-Time History in the Dead-End Space of the 20cm-Dead-End Magazine.

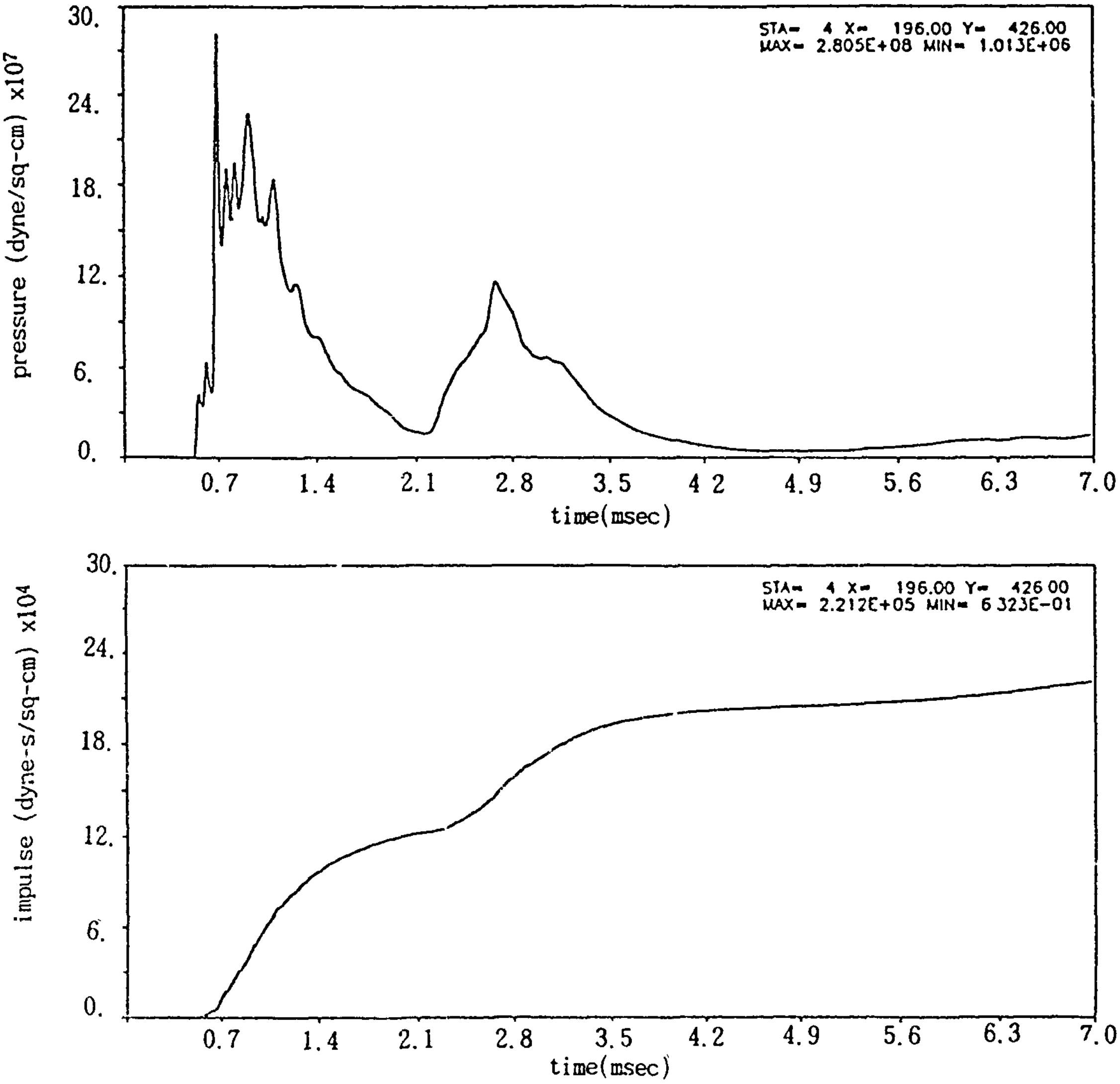


Figure 6. HULL Code Simulation of Pressure-Time History in the Dead-End Space of the 20cm-Dead-End Magazine.

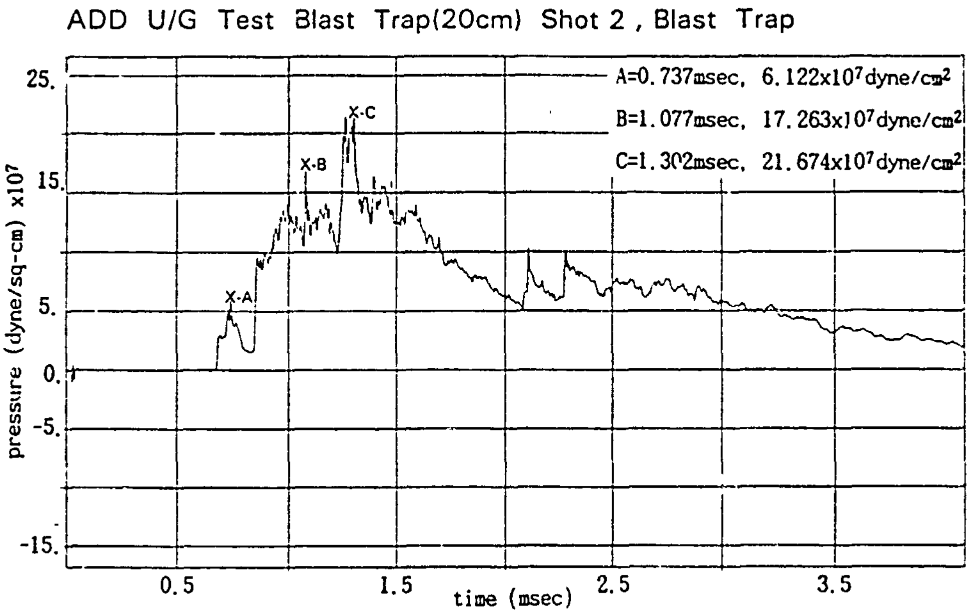


Figure 7. Experimental Measurement of Pressure-Time History in the Dead-End Space of the 20cm-Dead-End Magazine.

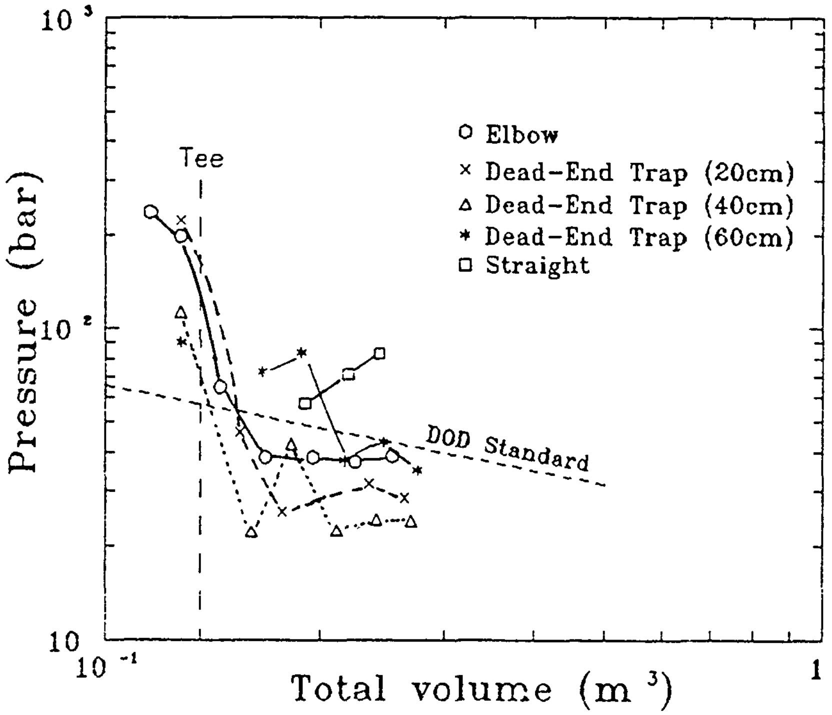


Figure 8. Measured Peak-Pressures in the Tunnel as a Function of Total Volume.

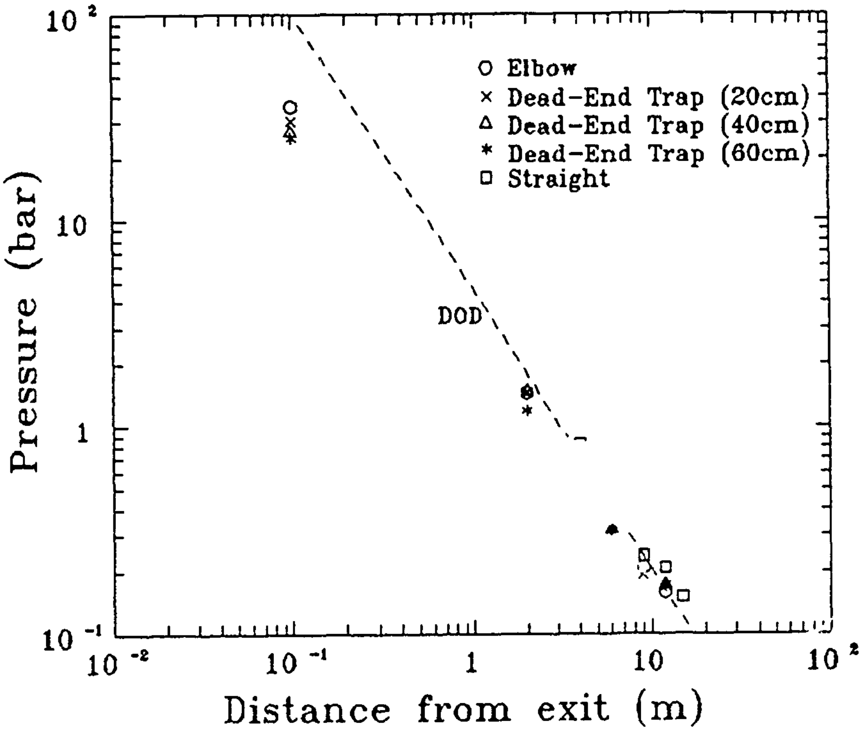


Figure 9. Peak-Pressure in the Free Field along the 0-Degree Line as a Function of Distance from Exit.

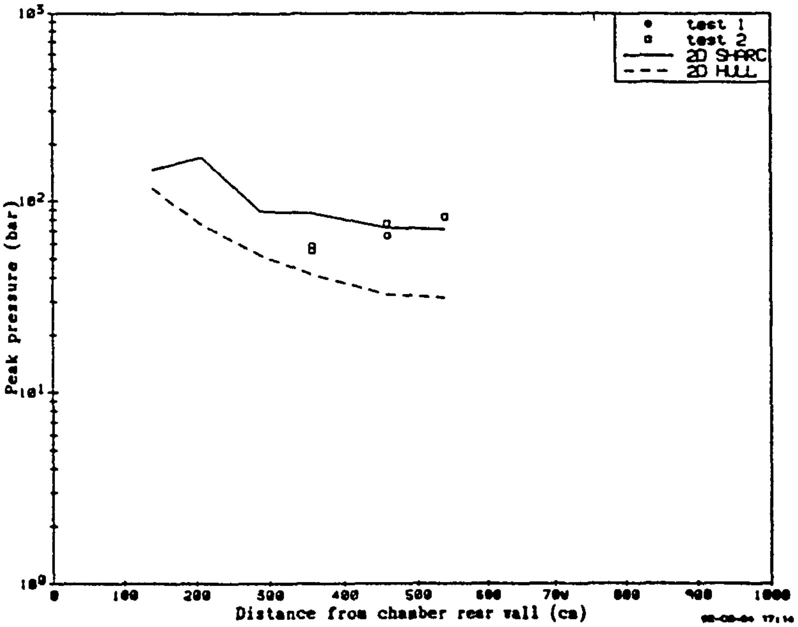


Figure 10. Comparison of Hydrocode Calculations with Experiments for Straight Magazine.

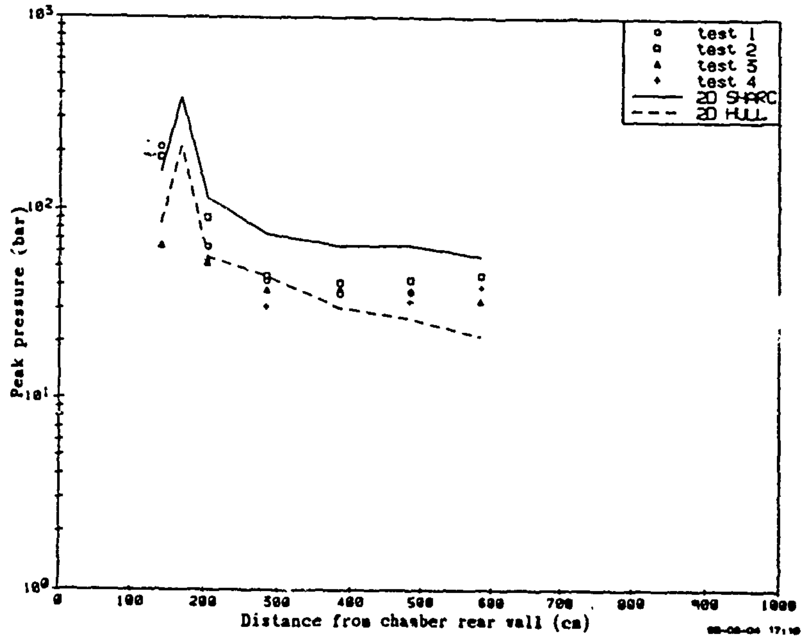


Figure 11. Comparison of Hydrocode Calculations with Experiments for Elbow Magazine.

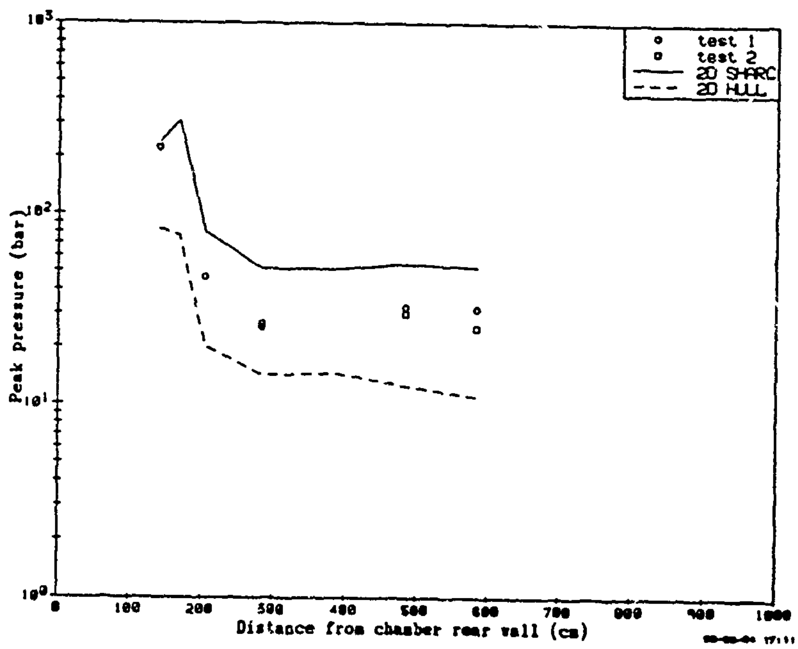


Figure 12. Comparison of Hydrocode Calculations with Experiments for 20cm-Dead-End Magazine.

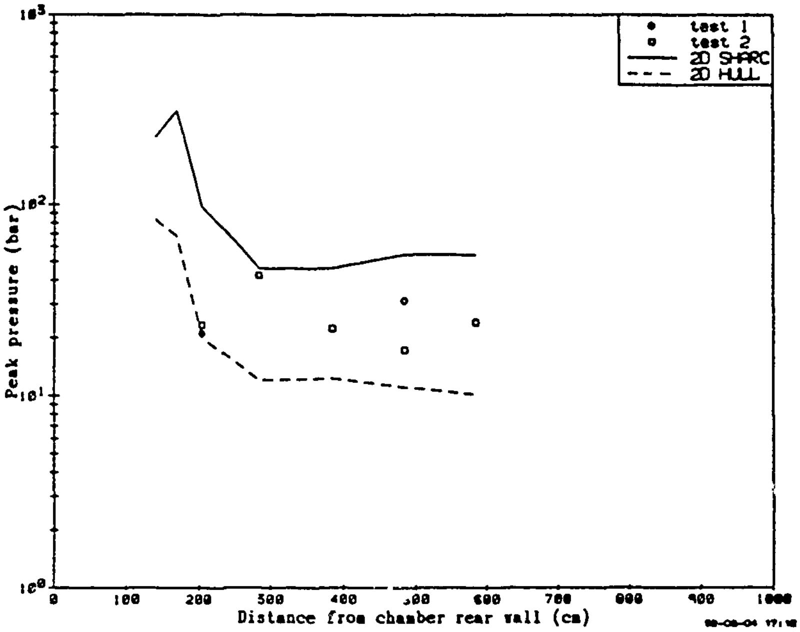


Figure 13. Comparison of Hydrocode Calculations with Experiments for 40cm-Dead-End Magazine.

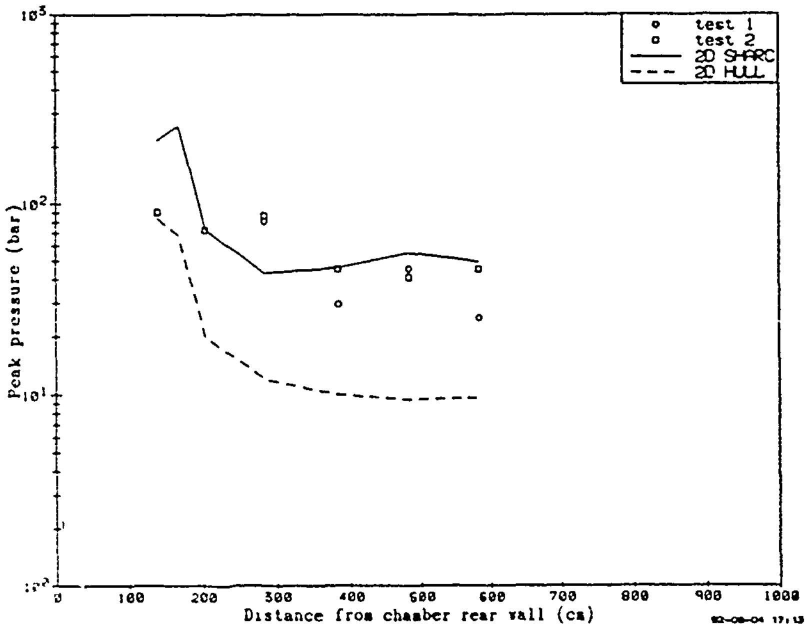


Figure 14. Comparison of Hydrocode Calculations with Experiments for 60cm-Dead-End Magazine.

BLAST ATTENUATION EFFECTS OF ACCESS TUNNEL CONFIGURATIONS FOR UNDERGROUND MAGAZINES - A PARAMETER STUDY

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ABSTRACT

During recent years, the U.S. Army Engineer Waterways Experiment Station (WES) has performed hydrocode calculations to study blast and shock effects resulting from accidental explosions in underground magazines. This paper presents the result of a parameter study conducted by the author (during an assignment as a visiting scientist at WES) with the 2-dimensional version of the SHARC hydrocode. The study evaluated the effects of access tunnel configurations on airblast attenuation at the exit. A single magazine calculation (400,000-kg TNT charge within a chamber volume of 7500 m^3, giving a loading density of 53.3 kg/m^3) provided input for the various access tunnel configurations studied. The study evaluated the effects of different tunnel lengths and cross-sectional areas, expansion chambers and multiple exits. Implications of the results for Quantity-Distances (Q-D) are discussed.

INTRODUCTION

In the design of underground munition storage magazines, the possible effect of an accidental explosion is given considerable attention. Much work has been accomplished to improve the safety aspect of such magazines, both to reduce the risk of an explosion and, if an explosion does occur, to reduce the external hazards and damage. In a deep, underground magazine, the greatest hazards from an explosion are the high-velocity debris and high pressures vented through the tunnel portal.

Several countries, for instance Norway and Germany, have conducted extensive model tests and hydrocode calculations to study these effects, however, the study presented in this paper is only concerned with the airblast effect at the tunnel portal. The study was performed by the author at the U.S. Army Engineer Waterways Experiment Station (WES) with the 2-dimensional version of the SHARC hydrocode, to evaluate the airblast attenuation effects in a range of different access tunnel configurations. Due to the large, time consuming calculations, the study has been restricted to the pressure attenuation. Other important parameters such as the airblast duration and impulse, have therefore been given little attention.

SHARC-CALCULATIONS

A single storage chamber calculation provided input for the various access tunnel configurations studied. The charge weight considered was 400,000 kg TNT within a chamber volume of 7500 m^3, giving a chamber loading density of 53.3 kg/m^3. Figure 1 shows the dimensions of the magazine and the location of the charge, which was initiated close to the rear wall of the storage chamber.

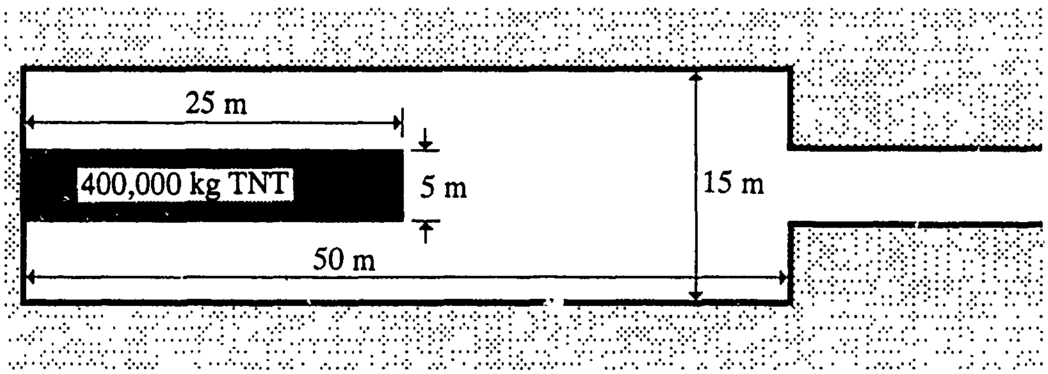

Figure 1. Ammunition storage chamber and explosive charge as represented in the calculations.

The chamber shock and gas pressure environment developed in this calculation were used as input to all the different access tunnel configurations considered.

All calculations were conducted with the same total volume, since the total loading density, i.e. the charge weight divided by the total volume of the facility (chamber plus tunnel), is generally believed to be a more important parameter than the chamber loading density. To satisfy this condition, both the chamber and the tunnel volume - including any expansion chambers - were held constant in the calculations, giving a total loading density of 10.4 kg/m^3.

In the study, the following overall access tunnel layouts were investigated:

- "Shot gun"-type magazine with a straight tunnel
- Straight tunnel with expansion chamber between the storage chamber and the tunnel exit
- Tunnel with a 90-degree bend
- Tunnel with a 90-degree bend and two exits

RESULTS

"Shot gun"-type magazine

The airblast attenuation effect and the exit pressure were studied on four different "shot gun"-type magazine configurations, as seen in Figure 2. In order to keep the total volume constant, the tunnel cross sectional areas were varied with a corresponding change in the tunnel lengths.

The results of the calculations are summarized in Table 1. From the results, it is seen that all configurations produced approximately the same exit pressure (Pe). Thus, for this type of magazines, the exit pressure seems to be strongly dependent on the total loading density, and not the tunnel dimensions.

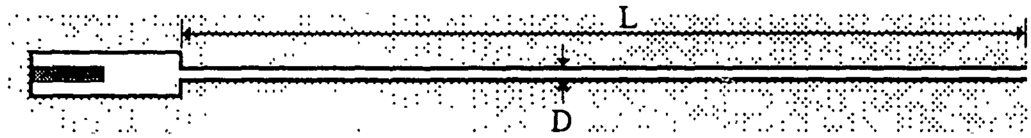

Figure 2 Layout of the "shot gun"-type magazine used in the calculations.

Calculation no.	D (m)	L (m)	Pe (MPa)
1	15	206	12
2	10	309	11
3	5	618	12
4	3	1030	11

Table 1 Exit pressures from calculations with different L and D, as defined in Figure 2.

Expansion chamber

Model tests with an expansion chamber in the access tunnel, between the storage chamber and the tunnel portal, have demonstrated that the exit pressure may be reduced significantly. For instance, Norwegian model tests (Reference 1) gave exit pressure reductions of 30 percent or more. This finding was also supported by previous SHARC- code calculations performed at WES (Reference 2). The WES calculations indicated that the geometry of the expansion chamber is of most importance, and the length of the chamber appears to be much more important than its diameter. Depending on the overall size of the expansion chamber, the WES study concluded that it should be possible to achieve peak portal pressure reductions of more than 60 percent. It should be noted, however, that in these calculations, the tunnel length on both sides of the expansion chamber were held constant, allowing the size and shape of the expansion chamber to be varied. This approach therefore provided different total loading densities in the different configurations studied.

In the new calculations reported in this paper, the shape and size of the expansion chamber were kept constant, only varying its location in the tunnel, in order to ensure the same total loading density in all calculations.

Four different tunnel configurations with expansion chambers were considered. The shock and gas pressure from the single magazine calculation were allowed to travel down the tunnel, through the expansion chamber, down the remaining part of the tunnel length and out the tunnel exit, as illustrated in Figure 3.

Table 2 gives the results of the configurations studied.

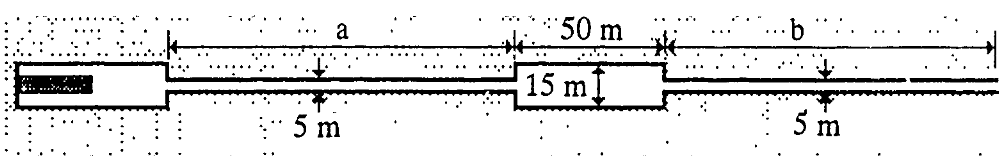

Figure 3 Layout of the tunnel with expansion chamber

Calculation no.	a (m)	b (m)	Pe (MPa)
5	100	368	11
6	150	318	12
7	200	268	11
8	300	168	9

Table 2 Exit pressures from calculations with different a and b, as defined in Figure 3.

As seen from the results, this layout provides exit pressures in the same range for all configurations. The only exception is the last calculations (a=300 m and b=168 m) which gave 20 - 25 percent lower exit pressures than the other configurations. No conclusion, however, may be drawn from this single calculation, and further configurations should be studied to evaluate this result.

The other expansion chamber configurations, however, gave results close to what were obtained with the "shot gun"-type magazines.

Tunnel with a 90-degree bend

One calculation was also performed to study the exit pressure in a tunnel with a 90-degree bend, as seen in Figure 4. The total loading density was kept the same as in the previous calculations. By introducing the bend in the tunnel, the exit pressure was calculated to be 8 MPa; a decrease of approximately 30 percent compared to the straight tunnel.

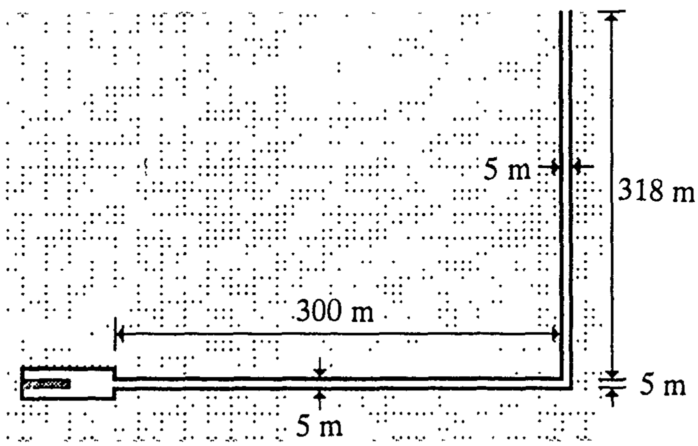

Figure 4 Tunnel with a 90-degree bend. The exit pressure was calculated to be 8 MPa.

Magazine with two exits

A magazine, similar to the one described above, but with two exits opposed to each other at 90 degrees to the main tunnel, was also investigated. Figure 5 shows the overall layout of the magazine.

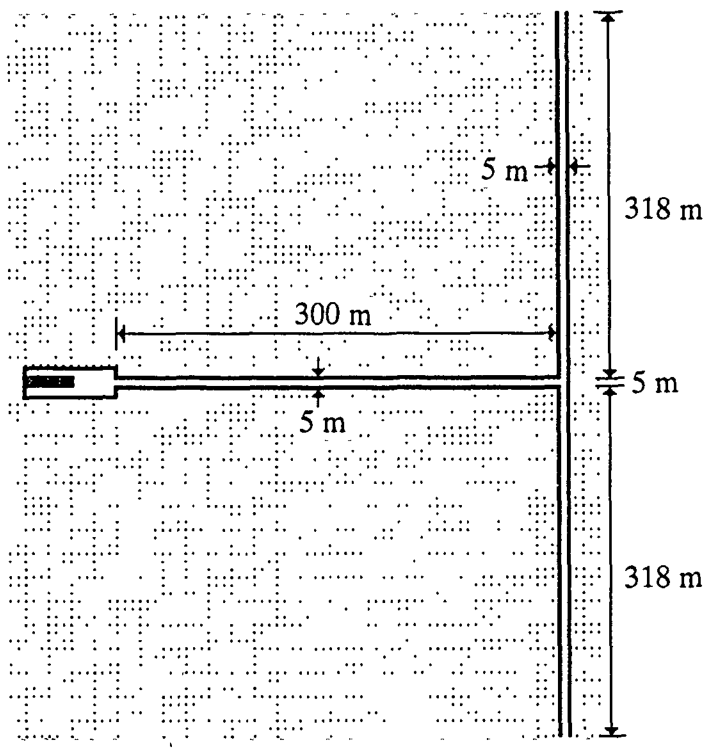

Figure 5 Magazine with two exits. The pressure at both tunnel portals was calculated to be 8 MPa.

The exit pressure for this magazine configuration at both tunnel portals was found to be 8 MPa, i.e. the same as for the magazine with one exit, described above. The reason for this is that the peak pressure in the tunnel mainly is determined by the peak pressure that exits the main chamber. Even though the magazine has two exits, the pressure attenuation is the same, since the shock front has to travel the same distance (or volume) to both tunnel portals.

SUMMARY AND CONCLUSION

The calculations performed in this study showed that pressure attenuation in straight tunnels - with or without any expansion chambers - mainly depends on the total loading density. Some of the existing formulae for calculation of exit pressure from explosions in underground magazines give a dependency on the chamber\tunnel diameter ratio. For the magazine configurations investigated, however, this ratio did not seem to make any contribution to the final result.

This study demonstrates that one way to reduce the peak portal pressure is to introduce a bend in the tunnel. For the 90-degree bend considered, the pressure reduction was approximately 30 percent compared to the "shot gun"-type magazine. The calculations also indicate that multiple tunnel exits will not give any further reduction in the peak portal pressure.

At this stage, the study has only been concerned with the pressure attenuation <u>inside</u> munition storage magazines. In order to achieve the airblast Quantity-Distances (Q-D) for the different magazines studied, the airblast attenuation <u>outside</u> the tunnel portal must also be considered. It is important to note that the external pressure attenuation is a function of both the peak pressure and the blast duration and impulse at the tunnel portal. Even though the exit pressure may be reduced by a change in the tunnel design, the wave form and duration of the airblast may also be changed. Therefore the change in Q-D may not necessarily be consistent with the change in peak pressure at the tunnel portal.

In the calculations presented in this paper, the expansion chamber configurations produced larger impulses than the other magazines studied. It is therefore believed that in this case, the tunnel with the 90-degree bend (with one or two exits) which gave the lowest peak portal pressure also will produce the shortest airblast Q-D.

REFERENCES

1. E. S. Helseth and A. Jenssen; "Underground Ammunition Storage Magazines, Blast Effects from Accidental Explosions", 1985, Fortifikatorisk Notat nr 179/85, Norwegian Defence Construction Service, Norway.

2. L. K. Davis and B. J. Armstrong; "Parameter Study for Expansion Chambers in Underground Magazines", U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, USA. (Report in preparation)

A Geographic Information System (GIS) for Explosives Facility Siting Analysis

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Abstract

Barricades, related facilities, segmented clear zones, waivers, and exemptions are just some of the problems faced daily by explosives siting analysts. The number of explosives locations in close proximity to operational and support facilities makes site selection one of the most critical issues relating to explosives safety. Yet, there is seldom time using conventional methods to examine all of the relevant options.

The use of Geographic Information Systems (GIS) has grown substantially in the last several years as the technology has matured to the point where it is relatively user-friendly, affordable, and accessible. The application of a GIS to the problem of explosives facility siting analysis has resulted in increased productivity, decreased errors, and the ability to detect problems that humans alone might overlook.

Introduction

Anyone who has attempted to analyze a site plan with a ruler and a calculator can testify that it is a process which begs to be automated. Not only is it tedious and error prone, but often the entire process must be repeated when the slightest change is introduced. Additionally, there is paperwork to type and revise with endless columns of figures that must be checked and rechecked. Many would agree that it is a task for which the computer is well suited. The question is how should it be applied?

The Air Force Explosives Hazard Reduction (EHR) Program Office at Eglin AFB, FL has been tasked to perform an EHR survey of several US overseas bases, the majority of the work to be performed by a small team of contractors from ISA with experience in explosives siting. Because of the magnitude of the effort and the pace of the schedule, the team also included a programmer to automate as much of the task as possible. The first EHR survey was recently completed, and the results of the experience and some of the lessons learned are presented herein.

The purpose of the EHR survey is to:

- Identify and quantify threats and operational restrictions posed by the presence of our own munitions stocks.
- Provide recommended approaches to reduce or mitigate these threats and restrictions.
- Recommend initiatives for inclusion in the EHR program.

Because ISA was not tasked to develop hardware or software systems for general use, tools and systems were applied that were on hand at the time. Other systems were not considered because of the time and expense of acquisition and training. Accordingly, these discussions will be presented in as general terms as possible so as to benefit those with different requirements. It should be emphasized that this was not a normal life cycle software development project taking years, but an on-the-fly effort where the software necessary to perform a certain task was usually started and finished on the day before it was needed. This quick turnaround sometimes led to false starts and blind alleys, but also to a kind of synergism between user and programmer that resulted in innovative solutions to complex problems. It also led to the realization that it takes less effort to automate many tasks than it normally takes to perform them even once.

Background

A GIS is an information system that is designed to work with geographically referenced data. It can be thought of as a higher order map which includes both a spatially referenced database and a set of operations for manipulating it at computer speeds.

The target hardware was an Apple® Macintosh™ running a MapGrafix™ computer-aided mapping system linked to a 4th Dimension™ database. The team utilized four Macintosh™ computers ranging from the SE to the IIfx. All

were equipped with large screen monitors to facilitate working with maps and large spreadsheets of data. Output devices included an "E"-size HP pen plotter, three laser printers and a small portable ink-jet printer for field operations. Paper maps were digitized with the aid of a Kurta "E"-size digitizing tablet.

Custom programming was added to MapGrafix™ in the Pascal language and to 4th Dimension™ in its scripting language. Over an eight month period approximately 10,000 lines of code were written to enhance and customize the GIS, and another 5,000 were written for the database.

The Pascal code automates the process of digitizing base maps by providing templates for standard explosives enclosures and other facilities. It can automatically produce a report with the distances and exposures between every potential explosion site (PES) and all respective exposed sites (ES) within a user defined distance. If barricades have been digitized, the report will also show if a particular building pair is barricaded or not, and notes the identifiers (IDs) of the barricades involved.

The database code streamlines the data entry of information pertaining to individual base facilities, waivers and exemptions, and separation criteria tables. It automates the calculation of quantity distance (QD) and provides searches for finding the problem facilities. Information is output to the map which automatically creates clear zones around the selected facilities. Lists of building pair (PES-ES) data can be exported for inclusion in reports, and AF Form 943's can be printed on a laser printer. The system can also generate an assessment of risk to each facility from all nearby potential explosion sites. The risk assessment, at this point, is based on computed separation factor and a table of estimated damage by structure type. The computed separation factor is given by the distance between the PES and the ES divided by the sited net explosive weight (NEW) raised to the one third power.

Computerization

All tasks performed with the aid of a computer can be divided into three stages: input, process, and output. Input or data entry, in this context, is an extremely technical process which requires knowledge and experience relating to explosives siting. The old saying, "Garbage in, garbage out" applies, and only careful attention to detail can prevent small errors from being magnified by the computer. The team found a small, but significant number of errors in the source data which could be located by cross referencing and looking for inconsistencies.

Processing is the part where all of the data has been input and automatic algorithms are being applied to produce results. Processing, usually the smallest portion of the task, is the most exciting part, since after weeks of entering and cross checking data, you can sit back for a few hours while the computer does all the work for you. This is what the general public thinks of when they think of data processing. Perhaps it is because of those early cartoons that depicted men in white lab coats with their feet up on desks in front of a giant mainframe, and a sign that reads "don't bother to think."

Output, of course, is traditionally the part where the computer produces reams of paper copy which is printed in neat rows and columns, bundled into boxes, delivered to the customer, and stored in some closet never to be seen again. For this reason, there is usually some kind of post-processing designed to reduce the results down and summarize them into some form with which humans can cope.

Collecting the Data

The first step in computerized site plan analysis is data collection. In our case it involved obtaining paper copies of base maps at a scale of 1:600 (1"=50') and 1:5000 (1"=416'). Copies of facilities development plans for future construction and five year capital improvement programs were also obtained. In addition we acquired lists and locations for electro-magnetic radiation hazards, explosive safety quantity-distance maps, and aircraft parking maps. In order to classify and compute QD for each facility we requested and received listings of the real property inventory detail lists, facility data records from munitions branch CAS-B records, and copies of all current and pending site plans, exemptions, waivers, and deviations. Other data of interest include: "As Built" drawings, bench mark coordinates, USAF Definitive Drawings, drawings identifying barricades by type, and a regional location map.

All totalled, this can amount to some thirty pounds of paper which must be forced into the computer against its will. Right about now, some people usually ask why this mountain of information can't be provided in electronic form. These are usually people who have never been involved with transferring information from one computer system to another. Here is a somewhat facetious test to illustrate the point. Suppose you call the safety office at the base you are about to survey and ask for all of the above information in electronic form, will the person on the other end of the line be more likely to: A) Ask what format diskettes would you like that on? B) Request a stock number. Or C)

laugh in your face. If you answered B or C, you have your feet firmly planted on the ground. If you answered A you may have a problem distinguishing reality and should consider a career in politics.

Digitizing the Maps

When some people hear the phrase "digitizing maps", they think that we are talking about scanning with a flat-bed or sheet-feeding scanner because that has become a relatively common process due to desk-top-publishing. What we are really talking about though, is taping the paper maps to what looks like a large draftsman's table and clicking on the endpoints of lines with a small hand held puck equipped with cross hairs. It is a process similar to solving a child's puzzle called connect-the-dots. This is the normal method in the GIS world, but it is seldom seen outside of it, and as a result outsiders are somewhat confused by it. They are often appalled by its labor intensive nature and the fact that it seems like a low-tech solution. The situation is complicated by the fact that there are now services to which you can send your maps, and they will be scanned and "auto-traced." If you do your furniture shopping at K-Mart, you will probably be really happy with an auto-traced map, because when you pick it up, you find that you still have to put it together.

Since one of the goals of the system is to automatically determine the orientation and exposures of PES to ES pairs, buildings must be digitized in a specific way. Buildings are entered as a series of corner points with lines connecting them for walls We arbitrarily chose to enter them in clockwise order with the front left corner entered first. This is important since the blast and fragment hazard is different for the front, side, and rear of many explosives facilities. All of the standard building types are entered with a computerized template mechanism that ensures that they are drawn in a consistent manner that the computer can later break apart into component pieces of front, side, rear, door, blast deflector, and so on. As a part of the process, the buildings are given IDs which serve as the computer's link between the database and the drawing.

Creating the Database

There are four files of data that must be set up before the automated analysis process can begin. They are the facility file, the facility type file, the separation criteria file, and the waivers and exemptions file. The facility file contains all of the information about a particular facility referenced by building

number, and is entered from scratch for each base surveyed. The facility type file contains a list of building types organized by categories, and may require updating to include local facility types not previously encountered. The separation criteria file is a table organized in rows and columns containing a separation factor and minimum distance entry from every PES facility type to every facility type. Its current size is around 12,000 entries, but it is expected to grow to around 30,000. The waivers and exemptions file contains a list of potential explosion sources and exposures affected by the waiver or exemption. A database might contain as much as 20,000 kilobytes (20 MB) of data.

Turning the Crank

Once the data has been collected and entered and the maps have been digitized and linked with the database, we can finally make the computer begin to pay for itself by applying algorithms to the data to automate the processes that were formerly done by hand. These algorithms are the real focus of this paper, since without them the GIS system would be only marginally useful. Therefore, it is necessary to examine them in some detail, and in somewhat technical language.

We begin with the fundamental problem of determining the distance between two facilities. Since the Greeks, it has been known that the distance between two points P_0 and P_1 in the Cartesian plane is given by:

Formula 1. $$d = \sqrt{(X_1-X_0)^2+(Y_1-Y_0)^2}$$

However, representing buildings as points does not yield the required accuracy for explosives site planning purposes. We must instead represent them as the line segments between the corner points of the outer walls. This implies there are an infinite number of distances between two buildings depending on where you measure. In the simplest case, we are only interested in the shortest distance since that will be the one which drives our requirements. A little thought will convince you that the shortest distance (or equal in the case of parallel walls) is always between a corner point of one building and a point on the wall of the other building. So if we have a formula to find the distance between a point and an line segment, we can simply take the minimum of all the distances between all of the corners in one building and all of the walls in the other and vice versa. Since we are dealing with line segments and not lines, we must use parametric equations.

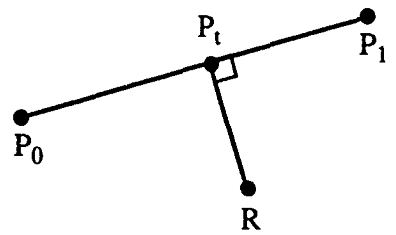

Figure 1.

The parametric affine equation of a line is given by:

Formula 2. $P_t = P_0 + t\,v$

Where v is the vector from P_0 to P_1, R is a point not on the line, and **t** is a parameter which varies from 0 to 1. Since the minimum distance occurs where the line from R to P_t is perpendicular to v, we can set the dot products of the two vectors equal to zero and solve for **t**.

Formula 3. $t = \frac{(R - P_0) \bullet v}{v \bullet v}$

If **t** is in the interval 0 to 1 then the perpendicular intersects the line segment and we can plug **t** back into Formula 2, solve for P_t and the distance is then given by $|R - P_t|$. On the other hand, if **t** is negative, the distance is $|R - P_0|$, and if **t** is greater than one, the distance is $|R - P_1|$.

The problem of finding distances between buildings is further complicated when one or both of the structures has a segmented clear zone. Segmented clear zones are the result of structural differences between the front, side, and rear of explosives enclosures. Explosives siting criteria, therefore, distinguishes between the required inhabited building distance (IBD) for a standard igloo, for example, by orientation, with the front sector being the most restrictive. This will be discussed in more detail later in the paper.

The parametric affine equation of a line is also useful for solving the problem of the intersection of two line segments. This is necessary when determining if a barricade falls between two buildings, and is also used for clipping a polygon to remove the portion falling on one side of a line. (Polygon clipping is a problem which occurs in computer graphics and detailed algorithms can be found in the textbooks of that field.) *Figure 2* shows the intersection of two line segments at a point P_t which is unknown:

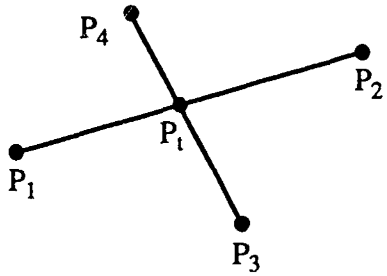

Figure 2.

Formula 4.1	$P_t = P_1 + tv$
Formula 4.2	$P_s = P_3 + sw$

Where v is the vector from P_1 to P_2, w is the vector from P_3 to P_4, and s and t are parameters which vary from 0 to 1. Since P_s and P_t are equal at the point of intersection, we can break the two vector equations into their scalar components and solve simultaneous eqations to eliminate the unknown in s giving:

Formula 4.3 $$t = \frac{Y_w(X_3-Y_1)-Y_w(Y_3-Y_1)}{Y_wX_v-X_wY_v}$$

Where the subscripts indicate from which vector or point (points are considered position vectors) the scalar components were derived. We then apply t to *Formula 4.1* to give the point of intersection. Astute readers will have noticed that the denominator of *Formula 4.3* is the determinant of the matrix of v and w corresponding to the vector cross product, and is zero only when the two are parallel. This must be checked first before applying the division.

Applying the Math

Armed with these two simple procedures for determining distance and intersection, we are now able to take on the task of determining the distances between two buildings with segmented clear zones and possible barricades in between. In contrast with the relatively simple mathematics presented above, the water now gets both deeper and murkier.

A simple case involving a segmented clear zone is illustrated below involving a hardened aircraft shelter (HAS) and another building. The HAS projects a clear zone in a 30° cone coming out of the front with the vertex placed so that the sides of the angles pass through the intersection of the door and side walls. Since the side of the cone passes through other building, there is both a front and side exposure, and we need to measure the distance of both.

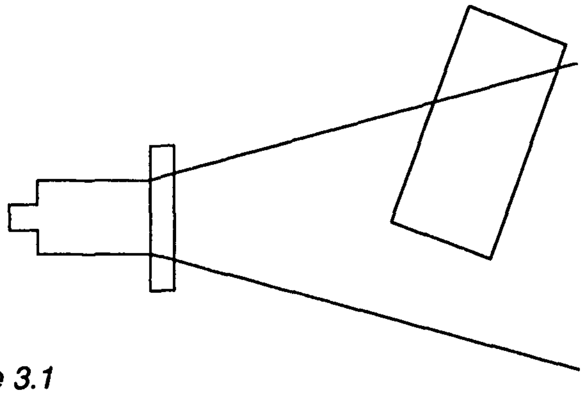

Figure 3.1

This is most easily accomplished by slicing the exposed building into two parts and applying our procedure for computing distances to each of the respective parts in turn. The distance measured from the front of the HAS is:

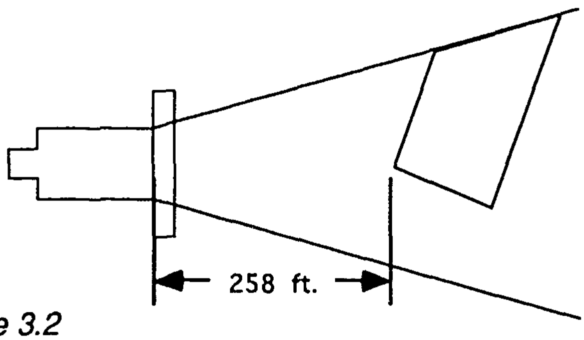

Figure 3.2

The distance measured from the side of the HAS is:

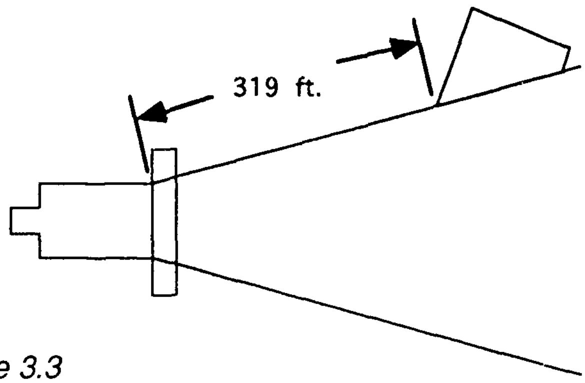

Figure 3.3

In order to go about slicing (or clipping) an arbitrary closed polygon with a line we must first develop a method for determining if a point is to the left or right of a vector.

Given two points P_0, P_1, and a point R just as in *Figure 2* we begin with the following general equation of a line:

Formula 5 $aY - bX - c = 0$
where $a = X_1 - X_0$, $b = Y_1 - Y_0$, and $c = aY_0 - bX_0$

Changing to inequalities, we find that $aY_R - bX_R - c < 0$ when the point R is to the right and > 0 when it is to the left (where left and right are as if you were standing on point P_0 looking toward P_1.) Of course, if $aY_R - bX_R - c = 0$ the point is on the line.

Clipping then, involves considering each point of the polygon in turn, keeping it if it is on the side we want, and removing it if not. Each time that we change from one side of the clip line to the other, we must compute the intersection of the current polygon side with the clip line, and retain that point.

Finding Barricades

Given that we have two buildings represented by polygons, we add a third polygon, possibly between the two, possibly not, which will represent a barricade. We wish to determine if any point on building A can connect to any point on building B without intersecting a barricade wall. While a general solution to this problem is not known to me, a rough approximation that works in almost all real world cases is as follows: Apply the intersection test to each line joining the corner points of A with the corner points of B, and every barricade wall. If any line fails to intersect at least one barricade wall, then the barricade does not completely protect A from B or vice versa.

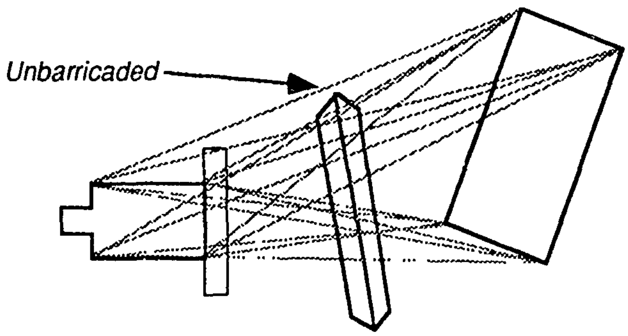

Figure 4

This procedure can be extended easily to handle multiple barricades, but it should be noted that limits must be placed on the distance that a barricade can be from a PES or ES because the effectiveness of a barricade diminishes rapidly with distance. The method can sometimes fail to detect small openings between multiple barricades. However, since that would constitute a design flaw in the barricade, it is assumed to be a rare occurrence. Barricade detection can add significantly to the processing time, since where there is one barricade, there are usually several hundred. Unless some optimization is applied to the process, it can easily take days of computer time. One optimization would be to keep list of barricades that are near enough to each building to be considered a candidate.

There are cases where we wish to know if one particular side of a building is barricaded, rather than considering the building as a whole. These are the same buildings that have segmented clear zones and require separate distance measurements, and so are handled by the same method of clipping the exposed building to the required arc and running the barricade test on the remaining portion.

Determining Exposure Faces

US Department of Defense Standard 6055.9 chapter 10, paragraph C2 states that "*A particular face of an ES is deemed to be threatened by a PES face when both of these faces lie within the arc of the threat or hazard of the other.*" Figure 5 shows two standard earth-covered magazines (igloos) whose front faces do not lie within the 120° front cones of the other, but which will have front distances output by our compute distance procedure, since some of the building will lie within the cone.

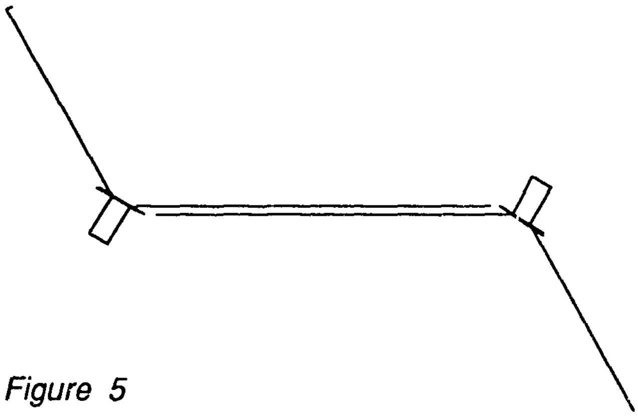

Figure 5

What is needed is to enhance our compute distance procedure for segmented clear zones to determine which faces are exposed, if the other building also has a segmented clear zone. Then we must compute the distances and exposed faces from the other building back to the first and eliminate distances to faces not within the arc of the other.

Determining which faces are exposed can be accomplished fairly easily for buildings that have a convex shape; that is, any building whose sides never face each other. After computing the distance from a particular segmented clear zone sector, we take the remaining part of the exposed building that lies within its arc and consider it one wall at a time. Beginning with the front wall and going clockwise around the structure, (since that is how we have standardized our digitizing process) we apply the procedure for determining if a point is to the left of a line. If either of the two endpoints of the source wall of the PES are to the left of the ES front wall (standing at the front left corner and looking along the door), then the source wall can be seen from the exposed wall, and the ES side is therefore considered an exposed face. The process continues around the ES until all sides have been considered.

After this process has been applied for each sector of the PES, and the ES faces exposed to each have been recorded, the roles of the PES and ES are reversed and the process is repeated until the exposed faces of each have been determined. Both lists are then checked against the other to eliminate distances to exposed faces that do not lie within the arc of the threat of the other.

It should be noted that all of the above algorithms have been simplified to the point where it is possible to explain them in simple English, and much work is needed to convert them into working procedures in any computer language. For instance, we have ignored the fact that the threat arc for the front of a hardened aircraft shelter is different when it is considered as a PES from what it is considered as an ES.

Priming the Database

After determining the distances and exposures, and noting the presence of barricades between each PES/ES pair, we then consider how this information can be processed for use in the explosives site planning analysis. One of the obstacles to the process is the problem of information overload. The computer obediently produces tens of thousands of lines of output which we must sort through to find the (hopefully) few hundred cases in which we are interested. Accordingly, the first step in analyzing our initial output is to transfer it to a database program.

In this process, data generated from the map is combined with data from other files to create records which completely describe the relationship between the building pairs. As the data is read into the **PES/ES** database file, the facility number of each is checked against the previously entered **Facility** file and the **Facility Type** of each is noted. The PES and ES Facility Types are used as indexes for the row and column of a table called the **Separation Criteria** file which contains the quantity-distance criteria derived from US Air Force and DoD standards. The table contains the **Separation Factor** (K-Factor or Q-Factor) for hazard class/division 1.1 munitions, the minimum allowable distance, and a field which contains note numbers of notes which detail exceptions and amplifications for this particular type pair. Note numbers are prefixed by a plus (+) sign if the note contains information which could result in the Separation Factor being increased or the minimum distance being decreased. The file contains separate entries for barricaded and unbarricaded building pair types. The Separation Criteria file is further broken out by exposure if a particular Facility Type has different criteria for each side.

Once we have the Separation Factor and minimum required distance, we can compute the factors which are the heart of our analytic capability, **Required Distance** and **Maximum Allowable NEW**. We use the formula: distance equals Separation Factor times Net Explosive Weight raised to the one third power. This formula gives the required separation distance for a particular Separation Factor and explosive weight. We also compute the maximum allowable NEW for a given actual distance and Separation Factor by the formula: NEW equals Actual Distance divided by the Separation Factor the quantity cubed. For multiple exposures, we compute the results of all, and use the most restrictive. In other words, we use the maximum allowable NEW which is smallest, or the required distance which is largest. It should be noted that the procedure is slightly more complex when dealing with so-called **Incremental Distance** criteria which are not smooth exponential curves, but the result is the same.

After computing the maximum allowable NEW and required distance, we must check to see if the actual distance is less than the required minimum distance. If it is, the maximum allowable NEW is set to zero, meaning that if the two building do not meet minimum separation requirements, then you cannot store explosives in the PES. If the actual distance is greater than or equal to the required minimum, and there is no Separation Factor criteria in the table (represented by a zero value), then a maximum allowable NEW by type is used from the Facility Type file.

The maximum allowable NEW that has been computed thus far applies to only one PES/ES pair. In order to find the true maximum for a particular PES, we must examine the maximums to each of the exposed sites, and take the smallest value. The facility number of the ES which yielded the smallest maximum allowable NEW is noted in the PES Facility record as the **Limiting Factor**. This information can be useful when we are seeking solutions to criteria violations.

Sorting out the Problems

The actual computerized analysis begins with a **Multi-Problem Facility Search**. This is a search applied to the entire database which produces a list of facilities that cause a criteria violation for more than one PES. This allows the analysts to concentrate their efforts on the worst problems first. On the initial run, it will often reveal data entry errors and problems with the criteria data or how it is applied, as well as legitimate violations. The results of the search can be output as a PES/ES building pair list sorted by ES so that you can go down the list and quickly determine what the problem is.

After you have pared the list down to mostly legitimate problems, you may wish to run a **Problem Facility Search**. This search will select all of the PES/ES building pair records in which the actual distance is less than the required distance, the computed maximum allowable NEW is less than the current sited NEW, or the building pair is waived or exempted. This produces a master list of all the potential problems, sorted by PES, that should be examined by the analyst.

Armed with a list of potential problems, the next step is to examine each by PES using the **PES/ES worksheet**. This is a spreadsheet-like screen which includes the Facility record data for the PES, and the PES/ES building pair data to each of the exposed sites. Changing a field like the PES's **Sited NEW** results in an immediate recalculation of required distances and maximum allowable NEW. The worksheet includes buttons for common preprogrammed searches, including special geometric searches for buildings with segmented clear zones, to reduce the PES/ES list to only those within a specified clear zone. There are also buttons and menu items for sorting, printing, performing user specified searches, and exporting the list to spreadsheets and other database programs.

When the analyst has a question about where a particular result came from, the **Detail Record** for that PES/ES pair is used. The Detail Record al-

lows the user to view most of the information about the PES, the ES, and their relationship on one screen. One button on this screen allows the user to review the criteria table data used in the computations, and to read any notes that are associated with the entry. If necessary, the computed results may be overridden and the record locked from future automatic updates.

Linking with the Map

All of the database screens described above include the capability to display the selected facilities on the map with the press of a button. This allows for better visualization of the problem, and provides a sanity check on the computer's calculations. In addition, buttons allow the user to select facilities on the map and display their database records. Therefore, the two-way link allows the database and map to act as if they were one program, while each maintains the capability to function separately.

One of the most important links between the database and the map is the capability to generate clear zones around selected facilities. Although it is possible to generate clear zones without the database, from within the map program itself, it is a cumbersome process when it involves multiple facilities of different types and net explosive weights. By using the database's searching and selecting capability, in combination with the built-in separation criteria tables, clear zones can be generated from each specified PES to a particular ES type. This allows the user to quickly determine where possible areas are for siting a new facility.

Choosing a Site for New Facilities

Once the candidate areas for the new site have been outlined by the clear zones of surrounding facilities, the user may create a new facility with the map template mechanism, choosing from any of the standard munitions enclosure types, and customizing it with dimensions from the "As-Built" drawings. A clear zone may also be grouped with the new building, if desired, and they can be rotated and moved to a position and orientation that fits. If multiple facilities are being sited, they can be created all at once, by specifying the number in each row and column, and their side-to-side and front-to-back separation distance.

After a site has been chosen and the new facilities have been placed, the procedure to compute distances and exposures can be invoked for the sur-

rounding facilities, and new records will be created in the database. After s additional information about the new facilities is entered, Air Force Form 943 s may be printed for inclusion in a explosives site plan approval package.

Summing up the Capabilities

The hazard reduction and explosives site planning analysis capabilities of this software makes it possible for a person with the proper background and training to perform tasks at a speed and level of accuracy that would be impossible to accomplish by manual methods alone. The task, however, is still difficult, exacting, and time consuming, and human insight remains the ultimate quality control. Those of you who rely on your knowledge and experience in this area for a livelihood need have no fears of being replaced. Instead, look to the computer to supplement and focus your talents on areas where they be most productively applied, and to allow you the time to consider creative solutions by removing the burden of tedious measurements and calculation.

SITING OF AN EXPLOSIVES ASSEMBLY AND STORAGE OPERATION FOR MAXIMUM UTILIZATION OF LIMITED AVAILABLE AREA

19 August 1992

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LTV Aerospace & Defense, Missiles Division

Site planning for explosives assembly and storage areas can be a rather routine administrative exercise associated with building a new facility, modifying an old or changing an operation or it can be a frustrating, lengthy exercise in futility.

The documents governing Explosives Site Planning will vary depending on where your facility is located, who owns it, who your contracts are with and who administers them. Most familiar to defense contractors in the U.S. are DoD 4145.26M, DoD 6055.9 Std., AR 385-64, AMCR 385-100, AFR 100-127 and OP5. Frequent users often find it hard to remember that these standards are in the final analysis,of the same origin! I've made an attempt on a number of projects to start fresh and try to "re-understand" references such as 4145.26M, however, when its deceivingly simple text is applied to a real facility it never fails to generate controversy. One might be tempted to believe that Explosives Site Planning is truly an art and certainly not a science.

When one begins with a specific mission and an empty tract of desert, explosives site planning can be simple. Fences can be erected at an outer perimeter, past the outermost hazard arcs. Operating lines and magazine areas can be separately by an ideal inhabited building distance and the overall facility can be made to best accommodate the product to be manufactured or stored.

Such an opportunity is becoming an increasingly rare event in our cooling business climate. Consolidation of contracts, aging facilities, prime storage areas being filled with ammunition stocks returned from OCONUS, greater public concern and awareness and a moratorium on waivers are some of many factors requiring us to be more resourceful and precise when siting or re-siting an explosives facility.

Much can be done to profitably and safely utilize facilities that appear at first glance less than adequate for explosives operations. Two categories of action should be taken to reach this optimum level of utilization; first, understand and apply all of the existing standards and then, utilizing new engineering approaches, modify facilities and/or analyze existing ones to determine their actual characteristics with regard to the explosives materials to be stored or processed.

Existing standards such as 4145.26M, OP5 and AMCR 385-100 must be thought of as manuals that tell what <u>can</u> be cone rather than lists of restrictions. By their very nature, however, each focuses on the originator's particular need and may not always be broad enough to satisfy the task at hand. Mindful that virtually all such documents are fundamentally consistent when it comes to essential principles such as quantity-distance and allowable exposures, it is to ones advantage to consult all available references to form a clear picture.

Careful planning of work elements should consider factors that effect QD and unacceptable exposures. Minimize the quantity of explosives in work, waiting processing and awaiting delivery. Good planning in this area is fundamental to working where space is at a premium...reduce sited NEW. Just-in-time supply and prompt delivery to the customer are good business practices anyway. Plan the assembly of major end items to avoid the predicaments that would occur when, for example, a small 1.1 component is installed in a large 1.3 component. An example of this is to be found with a missile system at my company where a 1.1 component weighing less than a pound was installed in a missile with a nearly 400 lb. 1.3 motor. The assembly was 400 lbs. of 1.1 according to the interim hazard classification. QD arcs increased dramatically, especially with a number of assemblies in one facility. Simply planning the installation of the small 1.1 component for a different location (in this

case on the range where flight testing was to occur) solved the problem and allowed work to continue.

A magazine constructed too close to an operating building can be a problem. To maintain the required distance between the facility with a mixed load in the magazine, perhaps only a fraction of the magazine's capacity would be available. Schedule production so that only material to support the current production thus reducing the distance requirement to ILD from the operating line and greatly increasing capacity. Lease a temporary facility to store your other explosives in order to maintain compliance and maximize capacity.

Ensure that hazard classifications are correctly done. We've noticed a trend where items that are obviously not 1.1 are being classified as such because it's easy to do quickly. The penalty is that you must handle, store, and ship these items accordingly.

On the other side of the token, look for exemption opportunities on small items. Two such items in my Company's recent experience are a thermal battery and a gyro. These specific items had previously been classified as 1.4 and are now exempt. The benefit is obvious.

Many stock listed ammunition items have been tested and evaluated to determine actual characteristics. Listings can be found in documents such as AR385-64. An example from that list is a Nike Hercules missile. The HE Hercules has a NEW of about 5640 lbs. which would give you some impressive arcs at 1250 for the fragments and 790 feet for the IHB. The manual requires a distance of 900 feet for one round up to 1150 feet for 10 rounds. A Chaparral with a 1200 foot QD arc read off the tables requires only 400 feet for 10 rounds when using AR 385-64.

While you may not be working with specifically listed ammunition items, you may find that the propellants or explosive materials are quite similar and an analogy to justify a reduced distance is in order and can be applied for from the site planning approval authority.

A number of engineering/construction options are also available to modify structures or better evaluate their characteristics thus permitting more efficient utilization. Many older facilities were designed without need to consider now required fragmentation distances.

Low angle, high energy fragments may be stopped by adding a barrier and reducing the default distance drastically. Barrier design need not be an expensive task. By example, a facility needed by our company to build up some guided missiles with a 1.1 propellant was too close to other structures as it existed. An acceptable barrier design had to be found and erected in minimum time without a requirement to test its effectiveness. A visit to the Army Corps of Engineers Division in Huntsville, Alabama produced an inexpensive book and set of drawings entitled "Definitive Drawings, Barricades (DEF 149-30-01, 02 Dec 88). This document offers about 22 different barricade designs in all price ranges and degree of construction difficulty to adapt to a facility. In short order we had modified an otherwise excellent facility, increasing its capacity and rendering it suitable for 1.1 assembly work in a limited area.

Another option to consider when evaluating fragment throw distances is an analysis of both the primary and secondary fragment potential using a computer model and engineering study to document reduced distances. One such application was at a 10 year old facility on a GOCO operated by my Company that had been unknowingly encroached upon over the years. When work expanded in the area, particularly the need to introduce 1.1 material in item quantities of just over 100 lbs., a solution was needed.

Barricades as described in the previous example were not practical due to the size of the facility and the general terrain features.

Southwest Research Institute's engineers in San Antonio, Texas were consulted. Their evaluation and application of a Department of Energy funded program to model frag and debris throw from structures and their contents resulted in a significant reduction of hazardous blast over-pressure and fragment distances. In some cases distances were reduced by two-thirds, allowing us to expand our operation somewhat and avoid the cost of acquiring a whole new facility. Chuck Oswald from SWRI will discuss this program in another session.

Fragment throw is certainly easier to control than blast over-pressures but some options do exist to harden an exposed site to provide resistance to blast effects. Buildings that are structurally hardened to a specific level as determined by test or analysis may be located much closer to a PES. Because of the characteristics of shock waves and pressure fronts, care must be taken not to make assumptions about the capabilities of protective works. It is essential to work with an engineering firm experienced in this field when designing hardened facilities or modifying existing buildings to meet new requirements.

In summary, there are a number of options to be considered when faced with having to site an explosives assembly and storage operation to obtain maximum utilization in a limited area while providing optimum protection of our people and property.

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UNCERTAINTIES AND PROBABILISTIC RISK ASSESSMENT OF EXPLOSIVE SAFETY

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INTRODUCTION

The structural response, breakup, debris dispersion, and hazards from explosions within above-ground and below-ground storage facilities cannot be predicted with certainty. Statistical descriptions of ejecta mass, initial velocities, angles, and aerodynamic parameters are used in the prediction of fragment density and safe distances. There are also well-characterized uncertainties in ground shock and airblast hazards from explosions. These fundamental uncertainties influence the modeling and analysis approaches that are appropriate for explosive safety hazard analysis and criteria development. By taking into account the sources of uncertainties and how important they are in affecting the predicted hazard outputs, probabilistic risk assessment methodology can be used to quantify the risks from explosive storage facilities.

This paper is divided into two parts. First, we develop a risk analysis framework for explosive safety siting and facility assessment. A mathematical model is presented that includes stochastic occurrences of initiating events for use in explosive safety risk assessment. The probabilistic model includes a site/facility representation for multiple hazards, damage/injury modes, and multiple debris impact.

Second, we discuss uncertainties in explosive effects and present the concept of reliability-based design for new facility construction. This paper includes probabilistic analyses of the uncertainties in external airblast environments and spall of reinforced concrete structures from conventional weapon explosions, summarized from a broader study of conventional weapon effects [Twisdale, Sues, and Lavelle, 1992]. Systematic and random components of predictive error are analyzed for free-field airblast (peak pressure and impulse) and normally-reflected pressures. Range-independent prediction errors are shown to be acceptable. The statistics for both peak pressure and positive impulse support the use of the lognormal prediction error model. Safety factors are presented for free-field airblast environments from exploding bombs. A probabilistic spall prediction model is summarized, including reliability-based safety factors for design against spall effects.

PROBABILISTIC RISK ASSESSMENT OVERVIEW

For frequent events, risk can be determined based on an actuarial analysis of experience. For infrequent events, risk is assessed through deductive modeling, coupled with analyses of both simulated and experimental data on individual parts of the hazard event sequence. One of the risk assessment technologies that has become applied in many safety analyses (nuclear power, space operations, nuclear weapons safety, to name a few) is Probabilistic Risk

Assessment (PRA). PRA is the process of identifying the events that could endanger health and safety, estimating the frequency at which those events are expected to occur, and determining the consequences of those events [Hickman, *et al.*, 1981].

The elements of an explosive safety analysis within the context of a PRA are illustrated in Figure 1. Based on knowledge of the facility and operations, the starting point is the scenario analysis to identify what can go wrong. The identified initiating events and resulting accident sequences are generally analyzed through a combination of event trees and fault trees. In explosive safety, this analysis produces information on the state of the explosive source, such as the net explosive weight for each event sequence. The response of the storage facility is analyzed through models of the internal loads, failure and break-up of the structure and debris throw. External hazards, which influence the consequences of the accident, include ground shock, blast, debris, and fire These hazards can be combined to form the final damage states, which are input into the risk assessment. The safety risks are computed as the product of the event probability and the event consequence, generally in terms of injuries, deaths, property damage, per year

PROBABILISTIC MODELING OF EXPLOSIVE SAFETY HAZARDS

In explosive safety analyses where the frequency of the initiating event can be estimated a mathematical framework is needed to estimate the damage or hazard frequency. Equations to estimate damage state frequencies are presented for random occurrences of initiating events.

A risk probability formulation for hazards that occur randomly over time is given by

$$P_T(\xi) = \sum_{N=0}^{\infty} P(\xi|N)\, P_T(N) \qquad (1)$$

in which $P_T(N)$ = probability of N initiating events during time T; $P(\xi|N)$ = probability damage state ξ (*e.g.*, lethal debris density) given the occurrence of the N events; and $P_T(\xi)$ = probability of event ξ during time period T. When one substitutes an appropriate stochastic process for $P_T(N)$ into Equation 1, and determines the conditional loading, structural response, and hazard probabilities $P(\xi|N)$ for all N, and then solves for $P_T(\xi)$, an estimate of the total probability for event ξ is obtained. In the analysis of explosive safety events over the time domain T, two elements are potentially important in the risk prediction. One is the initiating event arrival process, including the uncertainties inherent in the estimation of initiator occurrence rates. A second aspect regards the manner in which initiators are aggregated in the total risk calculation.

Alternative Stochastic Models. The most commonly applied stochastic model of initiators is the Poisson process, which is based on independence and identically distributed arrivals,

$$P_T(\xi) = \frac{(\nu T)^N}{N!} \exp(-\nu T) \qquad (2)$$

where ν = mean rate of occurrence. By substituting Equation 2 into Equation 1 and evaluating $P(\xi|N)$ from a union combination of independent events, *i.e.*

$$P(\xi|N) = 1 - [1 - P(\xi)^N] \qquad (3)$$

one obtains

$$P_T(\xi) = 1 - \exp[-\nu P(\xi)\, T] \qquad (4)$$

For $\nu P(\xi)\, T \leq 0.01$, Equation 4 can be approximated by the familiar expression

$$P_T(\xi) \cong \nu\, P(\xi)\, T \qquad (5)$$

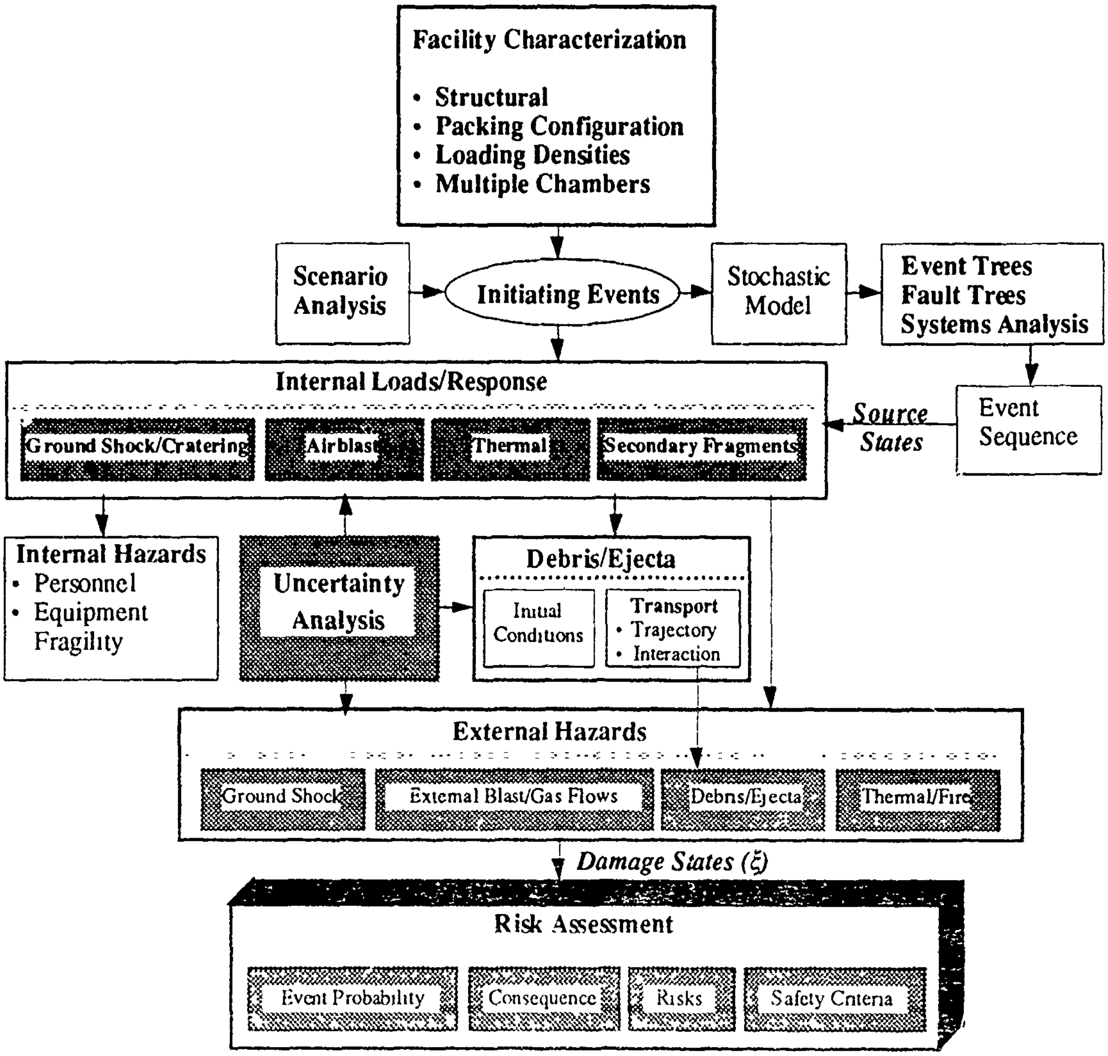


Figure 1. Probabilistic Risk Assessment of Explosive Safety Hazards.

with an accuracy of 0.5%.

In addition to the Poisson process, other stochastic models for initiating events include the Polya and Weibull processes, as noted in Table 1. Wen [1973] derived an expression for $P_T(\xi)$ using the Polya distribution, and Twisdale, *et al.* [1981] similarly deduced the Weibull risk expression in Table 1.

A common parameter for these stochastic models is mean occurrence rate ν, whose maximum likelihood estimator is $\hat{\nu} = n/t_0$ in which n = number of occurrences during time period t_0. The uncertainties on $\hat{\nu}$ can be analyzed by the methods of classical statistical analysis. However, to incorporate formally the uncertainty on the parameters of the tornado stochastic process in the risk model, a Bayesian viewpoint is useful, in which ν is treated as a random variable. In this approach the uncertainties on ν are specified by a probability distribution function $f(\nu)$.

TABLE 1. FORMULATIONS AND APPROXIMATIONS OF HAZARD RISK MODELS.

Arrival process	Risk expression, $P_T(\xi)$	Approximation to $P_T(\xi)$
Poisson: $P_T(N) = \frac{(\nu T)^N}{N!} \exp(-\nu T)$	$1 - \exp[-\nu P(\xi) T]$	$\nu P(\xi) T$
Polya: $P_T(N) = \frac{(\nu T)^N}{N!} (1 + \beta \nu T)^{-(N+1/\beta)} \prod_{k=1}^{N-1} (1 + \beta k)$	$1 - [1 + \beta \nu P(\xi) T]^{-1/\beta}$	$\nu P(\xi) T$
Weibull: $P_T(N) = \frac{(\nu T^\gamma)^N}{N!} \exp(-\nu T^\gamma)$	$1 - \exp[-\nu P(\xi) T^\gamma]$	$\nu P(\xi) T^\gamma$
Bayesian-Poisson: Gamma Prior $f_\nu(\nu) = \frac{t_0^{n+\kappa} \nu^{n+\kappa-1} \exp(-\nu t_0)}{\Gamma(N+\kappa)}$	$1 - \left[\frac{1}{1 + \frac{P(\xi) T}{t_0}}\right]^{n+\kappa}$	$\left(\frac{n+\kappa}{t_0}\right) P(\xi) T$
Bayesian-Weibull: $\mu_\nu = \frac{n+\kappa}{t_0}$, $\sigma_\nu^2 = \frac{n+\kappa}{t_0^2}$, $\eta_\nu = \frac{n+\kappa-1}{t_0}$	$1 - \left[\frac{1}{1 + \frac{P(\xi) T^\gamma}{t_0}}\right]^{n+\kappa}$	$\left(\frac{n+\kappa}{t_0}\right) P(\xi) T^\gamma$

The Gamma distribution, with mean μ_V, variance σ_V^2, and mode η_V given as a function of n, t_0, and κ in Table 1, is a useful model for $f(V)$. The parameter κ adjusts $f(V)$ to reflect the uncertainties in the explosive safety initiator database. From Table 1, note that $\kappa = 0$ results in μ_V equal to n/t_0. The choice of the gamma distribution facilitates the processing of the uncertainty on V by

$$P'_T(N) = \int_0^\infty P_T(N|V)\, f(V)\, dV \qquad (6)$$

since the Gamma distribution is the conjugate prior of the Poisson distribution. Equation 6 represents the Bayesian distribution $P'_T(N)$, and can be solved to yield the Bayesian distribution of a Poisson process *(4)*. Substituting Equation 3 and $P'_T(N)$, obtained from Equation 6, into Equation 1 and simplifying yields the following expression for Bayesian-Poisson risk probabilities:

$$P'_T(\xi) = 1 - \left[\frac{1}{1 + \frac{P(\xi)\, T}{t_0}}\right]^{n+\kappa} \qquad (7)$$

This expression provides a means to treat uncertainty in the initiating event frequency into the risk calculation explicitly and thus incorporates both the statistical and judgmental components in the analysis. For small $(n + \kappa)\, P(\xi)\, T/t_0$, Equation 7 can be approximated as noted in Table 1.

A Bayesian risk model for the Weibull process has also been developed using the Gamma distribution to model $f(V)$, as shown in Table 1. The selection of a particular risk model from Table 1 for a site assessment

should be governed by the characteristics of the available database.

Aggregation of source states. One formulation of the safety hazard risk uses the mean occurrence rate, ν, for all explosive source states and the calculation of $P(\xi)$ in Equation 4 using the total probability equation:

$$P(\xi) = \sum_i P(\xi|I_i)\, P(I_i) \qquad (8)$$

in which I_i = source state category i. This approach represents an aggregated ν formulation.

An alternative formulation is the treatment of each source state as a different event. In this approach, the stochastic models employ ν_i, the annual rate of occurrence of category I_i. The risk calculations yield $P_T(\xi_i)$, which is interpreted as the probability that event ξ occurs at least once in time period T from category I_i. The total risk probability from all intensities is given by

$$P_T(\xi) = P_T(\xi_1 \cup \xi_2 \cup \cdots \cup \xi_{i_{max}}) \qquad (9)$$

which can be accurately approximated by

$$P_T(\xi) \le \sum_{i=1}^{i_{max}} P_T(\xi_i) \qquad (10)$$

for small $P_T(\xi_i)$. Equations 9 and 10 represent a nonaggregated ν approach to the total risk calculation.

In view of these alternative total risk formulations, an important question in the risk calculation regards the predicted differences of the two approaches. It can be shown that for the Poisson and Weibull risk models, both the ν (aggregation) and ν_i (nonaggregation) formulations yield identical $P_T(\xi)$. For the Polya process, strict equality cannot be shown, but the two approaches give similar results for small $\nu_i P(\xi_i)T$.

For the Bayesian risk models, the ν and ν_i approaches do not yield identical risk probabilities for the Bayesian-Poisson or Bayesian-Weibull processes with a Gamma prior. It can be shown that the aggregation approach always overpredicts the risk probability when compared to a total risk prediction based on individual occurrence rates. In general, for rare events, the differences are less than a few percent and the manner of the total risk calculation is probably secondary to the treatment of errors and uncertainties in the data record, *e.g.*, the κ parameter. However, for situations involving short data records relative to design life T and/or the dilution of the occurrence record with source state intensities that do not contribute to the hazard events of interest, Bayesian risk probabilities should be calculated using ν_i and aggregated by Equations 9 or 10.

Site and Multiple Hazard Considerations. The damage state ξ often reflects potential injury or property damage events that could result for several hazards and may involve multiple facilities at a site. In this case, we can develop expressions that explicitly describe the risk at a particular site. We note, however, that if the objectives of the risk analysis is simply to quantify a single hazard, independent of the site structures, housing, etc. within the hazard region, then the following expressions will not be needed. These expressions are given for a general site/specific risk assessment when one is interested in taking advantage of protection and various levels of structural resistance occupant protection.

First, we consider the need to combine risks from multiple hazards that contribute do damage state ξ. As indicated in Figure 1, there are four basic explosive safety hazards

that affect the site surroundings. These are combined as

$$P_T(\xi) = P_T[\xi_g \cup \xi_b \cup \xi_d \cup \xi_t] \tag{11}$$

where $\cup$ = union set operator and the subscripts g, b, d, and t denote ground shock, blast, debris, and thermal hazards. A conservative approximation to Equation 11 is

$$P_T(\xi) \leq P_T(\xi_g) + P_T(\xi_b) + P_T(\xi_d) + P_T(\xi_t) \tag{12}$$

where each $P_T(\xi_i)$ is estimated from one of the expressions in Table 1, using an aggregated or non-aggregated approach. The approximation represented by Equation 12 should be used for small $P_T(\xi_i)$.

Second, for the case of explicit damage to other receptor or operator at-risk facilities, a site model could be developed that include each receptor as a damage event for that site, *i.e.*,

$$\xi = C_1 \cup C_2 \cup \cdots C_j \cdots \cup C_r \tag{13}$$

where C_j denotes damage to the jth receptor out of a total of r at-risk components from the explosion. Each building could also be damaged from multiple failure modes, which would reflect the explosive hazards and building construction. These expressions are solved using a general Boolean solver in the PRA methodology.

Probability of Debris Damage. The debris produced from accidental explosions can include thousands of primary fragments and secondary missiles. In a risk assessment, it may not be feasible to simulate each fragment or debris piece. A sampling method has been developed by Twisdale [1988] in which each potential missile at the site is treated as an indistinguishable (non-ordered) point in the sample space (*e.g.*, Feller, 1960). Estimators of single missile damage probabilities are obtained for each zone. By assuming independence among the multiple missile damage events and missile origin zones, the probability of the jth building damage due to impact effects is

$$P(C_j) = 1 - \prod_{t=1}^{z} [1 - P(C_j, q_t = 1)]^{q_t} \tag{14}$$

where q_t = number of missiles in zone t, z = number of missile origin zones within the donor; and $P(C_j, q_t = 1)$ = damage probability for a single missile picked at random from the q_t missiles in zone t. Thus, a stratified sampling process is used to efficiently estimate the contribution of missiles according to origin zone. It follows that $\sum_{t=1}^{z} q_t = q$. The following fundamental inequality has been derived [see Twisdale, 1986]

$$\begin{aligned} &1 - [1 - P(C_j, q = 1)]^q \\ &\leq 1 - \prod_{t=1}^{z} [1 - P(C_j, q_t = 1)]^{q_t} \end{aligned} \tag{15}$$

and thus the use of a single zone to model debris origin from the donor is unconservative relative to the developed multizone sampling model. Typically ten to twenty zones will be adequate for most donor structures.

UNCERTAINTIES

The uncertainties in predicting explosive safety hazards include both model prediction errors and the inherent variability in explosive phenomena. The analysis of these uncertainties is an important part of a risk assessment. The following paragraphs present some results of a research project [Twisdale, Sues, and Lavelle, 1992] to analyze uncertainties in conventional weapon effects within the context of reliability-based design of protective structures.

Reliability-Based Design. The reliability of a protective structure or storage magazine is the probability that the loading effect is less than the structural capacity. Due to the uncertainties in the prediction of loads and structural response, the load effect E and

structural capacity C are uncertain, and the probability of failure, P_f, is simply

$$P_f = P(C - E < 0). \tag{16}$$

The concept of reliability-based design (RBD) for protective structures and the use of reliability-based design factors (RBDFs), or safety factors, as an integral part of the analysis/design process, follows directly from Equation 16. Hence, for acceptable structural performance, the design equation becomes

$$\psi \cdot C \geq \lambda \cdot E \tag{17}$$

where Ψ = RBDF on capacity and λ = RBDF on load effect. In some cases, a load factor of unity may be appropriate, whereas in others the load and capacity factors may be combined into a single factor. In general, a table of Ψ and λ values are provided corresponding to different levels of reliability, P_s, where $P_s = 1 - P_f$, for each failure mode. A value of P_s is selected consistent with the explosive safety criterion or risk analysis results (which would consider the consequences of failure and cost-risk tradeoffs). Figure 2 illustrates this process of developing RBDFs through the analysis of uncertainties in traditional design methods. A key advantage of the RBD approach is that optimized safety designs can be developed, whereas the traditional approach produces unknown safety margins. Reliability-based methods thus provide the designer with knowledge of the degree of conservatism or unconservatism in the design and ideally fits into a risk-based explosive safety philosophy. The benefits of reliability-based design are well-recognized in the structural and geotechnical engineering community and many major design codes have RBD formats.

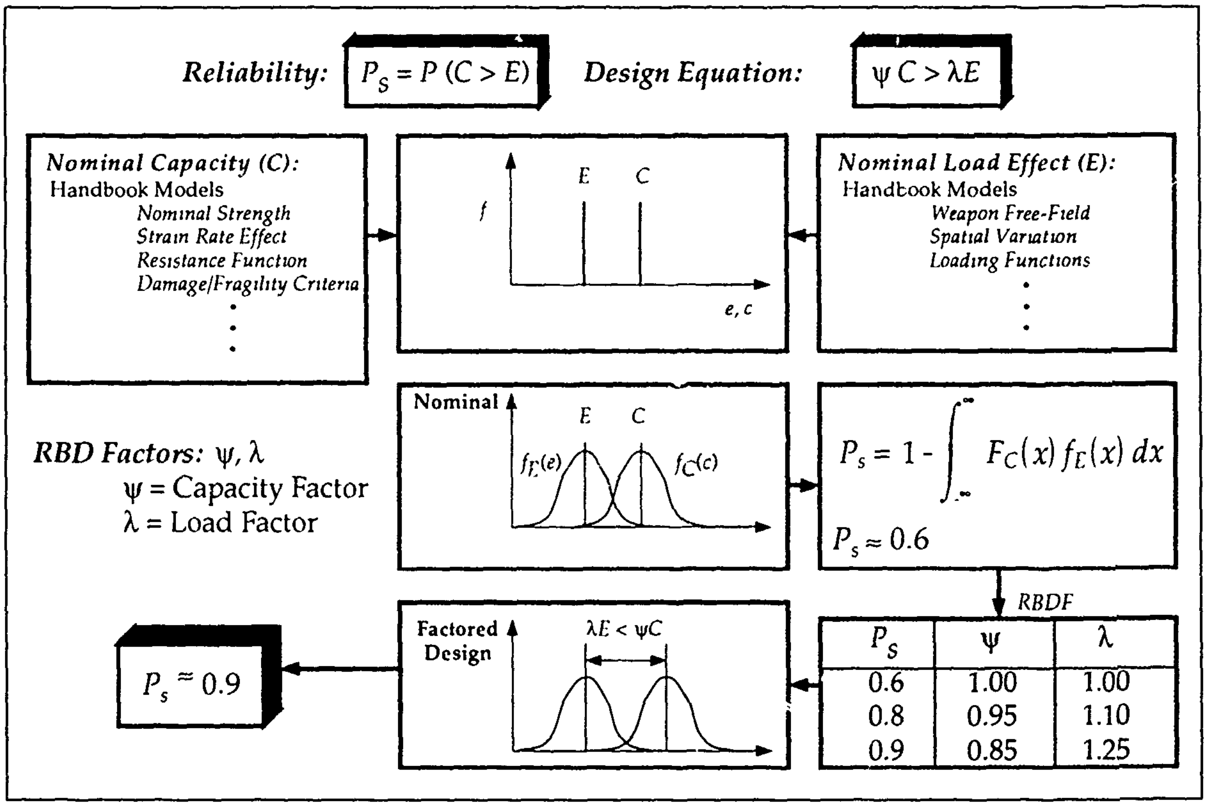


Figure 2. Development of RBD Factors for Use with Nominal Design Methods.

Free-field Airblast. The systematic and random errors associated with the deterministic incident airblast prediction methods recommended in the *Protective Construction Design Manual* [Drake, *et al.*, *1989*] for hemispherical surface bursts are summarized in this section, and load factors for incident pressure and impulse applicable to Mk82 and Mk83 general-purpose bombs are derived. To derive the load factors, prediction error models for incident peak overpressure and positive impulse are developed by directly comparing experimentally obtained airblast data to *PCDM* predictions. The experimental observations are from the Conventional High-Explosive Blast and Shock (CHEBS) test series [Carson, *et al.*, 1984; Carson and Morrison, 1987]. The CHEBS test series involved sixteen general-purpose (Mk82 and Mk83) bomb tests. Figure 3 compares the *PCDM*-predicted freefield peak pressure and impulse with the CHEBS data. Following analyses of these data, a final table of RBDFs was developed [Twisdale, Sues, and Lavelle, 1992] and is given herein as Table 2. Enough differences were obtained that separate factors were developed for the surface tangent and half-buried bombs. These factors are applied directly to the *PCDM* prediction equation. For example, for 95% reliability on predicted peak free-field pressure, the *PCDM* value should be multiplied by 1.55. If the *PCDM* value is used directly with no factors, about half the time the actual value will exceed the predicted value. Finally, we note that the uncertainties for predicting very low peak pressures, that are used in explosive safety siting criteria, could be significantly greater than those given herein.

Breaching of Reinforced Concrete Structures. Breaching of storage facilities is a common failure mode, and often a quick-checking formula is used to determine what net explosive yield will produce breaching of a wall or roof. Breaching failure modes are analyzed in the *PCDM* using empirical techniques developed by McVay [1988].

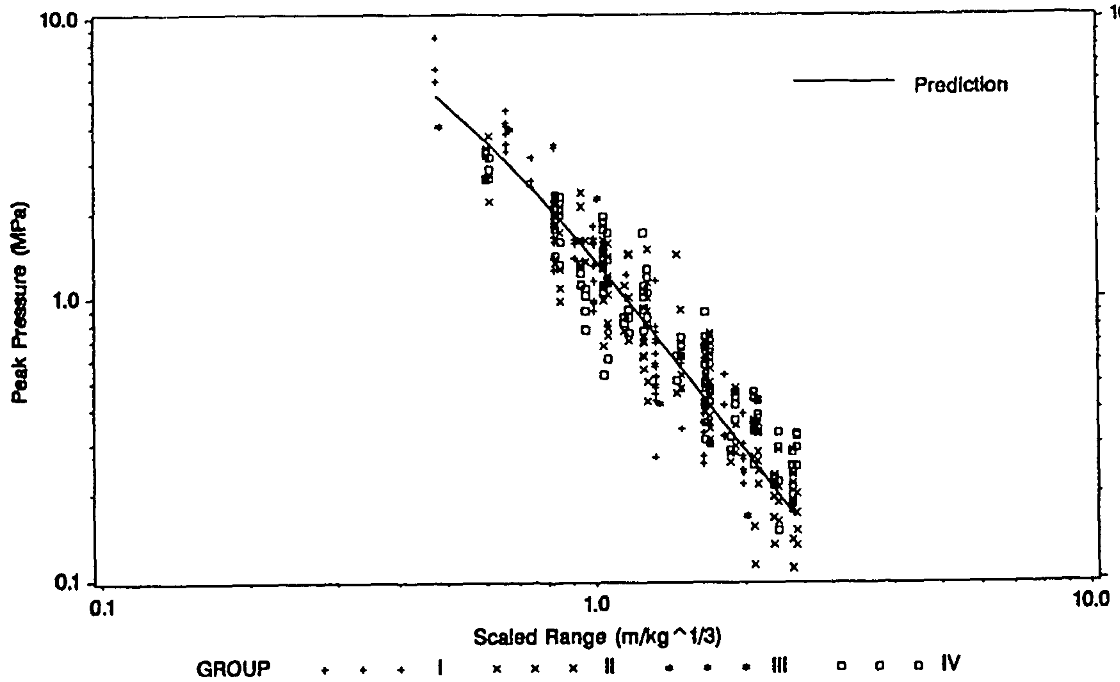
Figure 4 shows the basis of McVay's empirical analysis procedures used in the *PCDM*. McVay reviews empirical spall prediction methods, noting disagreements among the prediction curves in TM5-855-1 and a set of curves by Basler [1982] and Hader [1983]. McVay conducted forty new tests to augment the existing breaching/spall database. The No Damage-Spall-Breach areas in Figure 4 were then drawn by eye. Based on the range of the data, McVay [1988] developed Table 3 to show the range over which the procedures are valid. We caution that the majority of these data are for scaled model tests and, as pointed out by McVay, model tests may suffer slightly less damage than full-scale tests due to strain rate effects.

Using the *PCDM* approach, the designer can determine the wall thickness required to defeat breach and spall for a given yield and standoff. The breach and thickness prediction equations developed by McVay are:

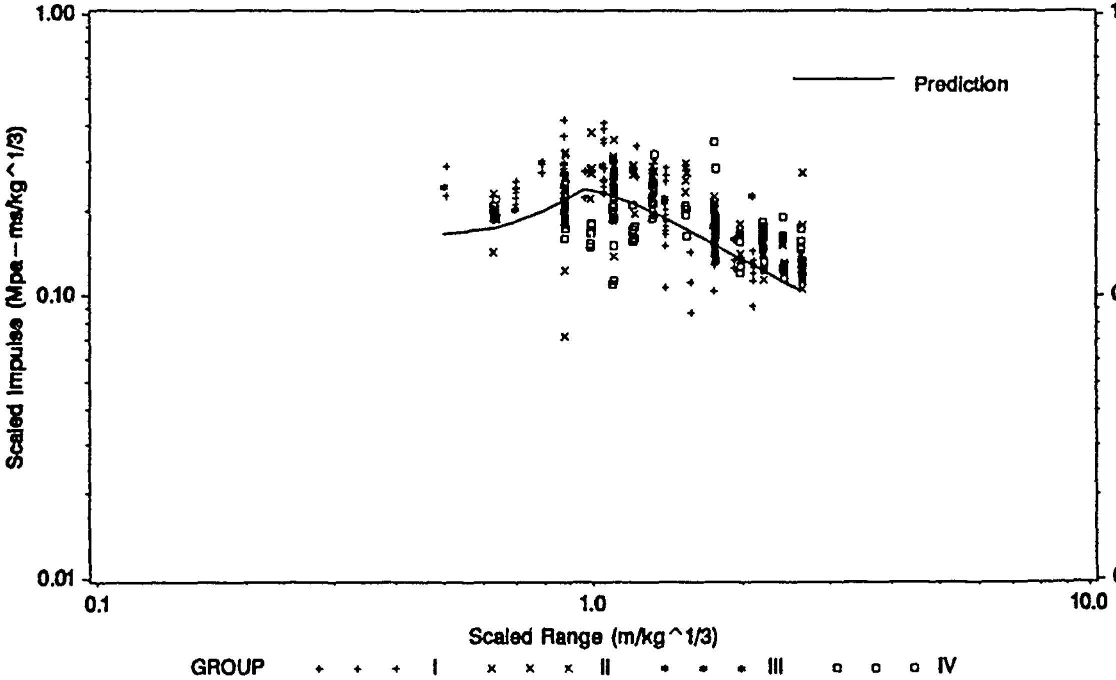
$$\frac{t_b}{W^{1/3}} = 0.23 \left(\frac{R}{W^{1/3}}\right)^{-0.3} \left(\frac{W}{W+C}\right)^{-0.3} \qquad (18)$$

where, t_b is the wall thickness to prevent breach (*ft*), W is the explosive weight (*lbs* TNT), C is the casing weight (*lbs*), and R is the bomb standoff (*ft*).

There are both systematic and random uncertainties associated with the *PCDM* empirical equations. The random uncertainty is visible in Figure 4 as the data scatter about the prediction model (*i.e.*, the solid damage lines in the figure). Systematic uncertainty is a bias in the prediction method. These uncertainties have been analyzed using a logistic form of dichotomous regression. Several prediction models were evaluated and we found that a simplified form of Equation 18 provided an excellent fit to the data, predicting the correct result (breech vs. no breach) about 87% of the time. The logistic model function $G = -11.6 \ln (t/t_b)$ produced the results shown in Figure 5. Because of the simplicity of these models, we were able to



a. Peak Pressure.



b. Positive Impulse.

Figure 3. ***PCDM*** **Predictions** ***vs.*** **CHEBS Observations.**

TABLE 2 INCIDENT AIRBLAST RELIABILITY-BASED LOAD FACTORS.

	Load Factor			
	Surface Tangent		Half-Buried	
Reliability	Pressure	Impulse	Pressure	Impulse
0.05	0.59	0.74	0.68	0.78
0.10	0.66	0.81	0.76	0.85
0.25	0.79	0.94	0.90	0.99
0.50	0.96	1.12	1.10	1.16
0.75	1.17	1.32	1.34	1.37
0.90	1.40	1.53	1.60	1.60
0.95	1.55	1.67	1.79	1.75
0.99	1.90	1.98	2.18	2.06

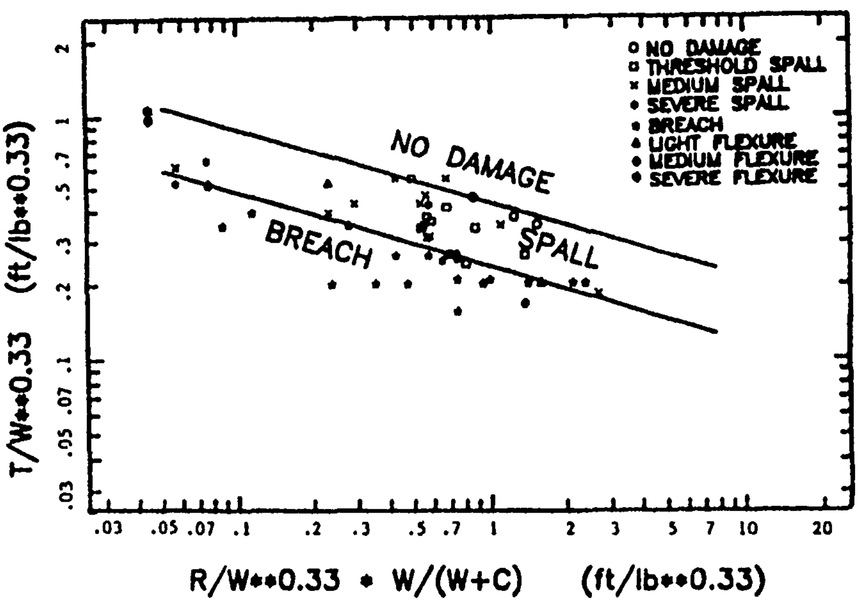


Figure 4. Damage to Aboveground Walls Due to Standoff Cased Bombs [after McVay, 1988].

derive a closed form expression for the design reliability that is a function of the wall thickness, t, and the *PCDM* design thickness, t_b. Given that all problem inputs are known (*i.e.*, R, W, C), the reliability of a wall of thickness t to resist breach from an explosion can be determined from:

$$R(t/t_b) = \frac{1}{1+(t/t_b)^{-11.6}} \qquad (19)$$

Using Equation 19, Table 4 lists the reliability-based design factors, t/t_b and their associated reliabilities that account for the breach model error.

As an example, suppose that a magazine wall is to be designed with 95% reliability to resist breaching at a scaled standoff of 1 $ft/lb^{1/3}$, for a charge weight is 175 *lbs* TNT,

TABLE 3. RANGES OF PARAMETERS FOR DATA IN FIGURE 4.

Parameter	Range	Recommended Use Range
Standoff distance	Contact to 30.0 *ft*	Contact to 7.5 *ft*
Equivalent TNT charge weight	0.824 to 2,299 *lbs*	0.824 to 220 *lbs*
Charge weight to charge plus casing weight	0.172 to 0.978	0.172 to 0.978
Scaled Standoff	0.077 to 12.06 $ft/lb^{1/3}$	0.077 to 5.00 $ft/lb^{1/3}$
Wall thickness	3.94 to 84.0 *in*	3.94 to 84.0 *in*
Scaled wall thickness	0.155 to 1.08 $ft/lb^{1/3}$	0.155 to 1.08 $ft/lb^{1/3}$
Static compressive strength of concrete	2,500 to 7,110 *psi*	2,500 to 7,110 *psi*
Principal steel ratio	0.11 to 1.34%	0.11 to 1.34%

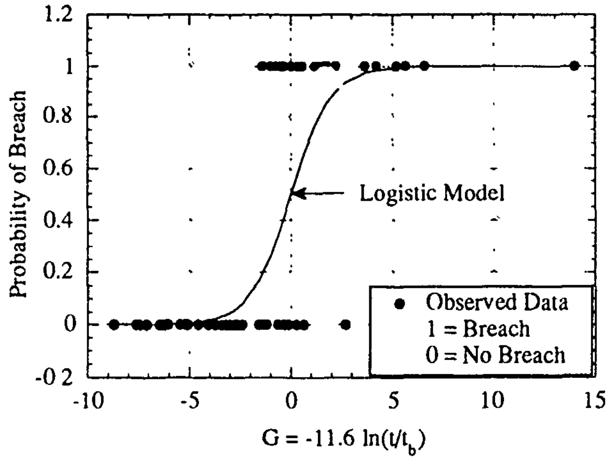


Figure 5. Logistic Probability Model for Breach for Standoff Cased Bomb.

and a charge-to-weight ratio of 0.35. First, from Equation 18, the nominal thickness to prevent breaching is found to be approximately 21 *in*. Next, from Table 4 (or Equation 19) we find that the RBDF for 95% reliability is 1.29. Thus, the nominal thickness of 21 *in* is multiplied by 1.21 to obtain a design thickness for $P_s = 0.95$ of 27 *in*.

SUMMARY

A mathematical framework for probabilistic risk assessment of explosive safety hazards has been presented. In this framework, the mean frequency and the uncertainties in the mean frequency of initiating events can be easily incorporated. The expressions in Table 1 summarize these hazard risk models. In cases where the initiating explosive event is assumed to occur with probability of one, the risk analysis reduces directly to the estimator of $P(\xi_i)$, the damage events of interest. Multiple hazard considerations include blast, ground shock, debris, and thermal effects, which can be aggregated by summing the probabilities of individual effects, provided these probabilities are all small. Multiple debris effects can be treated efficiently using a variance reduction sampling procedure, coupled with stratification of missile origin zones.

The modeling and analysis of uncertainties in explosive effects are an

TABLE 4. RELIABILITY OF WALL THICKNESS TO PREVENT BREACH FROM A STANDOFF CASED BOMB.[a, b]

Reliability[c]	$P_d(x)$	$G(x)$	RBDF t/t_b
0.05	0.95	2.94	0.78
0.10	0.90	2.20	0.83
0.25	0.75	1.10	0.91
0.50	0.50	0.00	1.00
0.75	0.25	-1.10	1.10
0.90	0.10	-2.20	1.21
0.95	0.05	-2.94	1.29

[a] t_b as defined by Equation 18 (*PCDM* deterministic prediction method).

[b] *PCDM* deterministic method and RBDFs are based principally on data from scale model tests. Additional research is required to assess the systematic bias and additional uncertainty due to the use of scale model data.

[c] Assumes all inputs to Equation 19 are deterministic.

important part of risk assessment. In this paper, uncertainty analyses and probabilistic models for predicting free-field airblast and breaching of reinforced concrete walls are summarized from a research project to develop reliability-based design methods for hardened structures. An end product of these analyses is a set of easy-to-use RBDFs that are applied to the predicted loads or response. We recommend that these recently developed RBD methods for protective structures be extended to cover the effects and hazards associated with explosive safety facilities. The RBD approach provides an ideal framework for the analysis and design of explosive safety facilities to meet risk based safety criteria.

REFERENCES

Basler, F. E., and Partner, *Lokal Schadenwirkungen and Betonplatten Durch Sprengladungen*, B3113.10-2, E. Basler and Partner, Zurich, Switzerland, 1982.

Carson, J. M., and Morrison, D., *Conventional High-Explosive Blast and Shock (CHEBS) Test Series: Mark-83 General Purpose Bomb Tests*, Air Force Weapons Laboratory, AFWL-TR-86-53, Parts 1-3, January 1987.

Carson, J. M., Morrison, D., and Hampson, R. J., *Conventional High-Explosive Blast and Shock (CHEBS) Test Series: Mark-82 General-Purpose Bomb Tests*, Air Force Weapons Laboratory, AFWL-TR-84-27, June 1984.

Drake, J. L., *et al.*, *Protective Construction Design Manual*, ESL-TR-87-57, Air Force Engineering and Services Center, Tyndall Air Force Base, November 1989.

Feller, W., *An Introduction to Probability Theory and Its Applications*, John Wiley, New York, 1960.

Hader, H., "Effects of Bare and Cased Explosive Charges on Reinforced Concrete Walls," presented at the *Symposium on the Interaction of Nonnuclear Munitions with Structures*, U. S. Air Force Academy, Colorado Springs, Colorado, 10-13 May 1983.

Hickman, J. W., *et al.*, *PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants*, NUREG/CR-2300, Nuclear Regulatory Commission, Washington, D. C., 1981.

Twisdale, L. A., Sues, R. H., Lavelle, F. M., *Reliability-Based Analysis and Design Methods for Reinforced Concrete Protective Structures*, Contract F08635-89-C-0121, Air Force Civil Engineering Support Agency, Tyndall Air Force Base, Florida, August 1992.

Twisdale, L. A., "Probability of Facility Damage from Extreme Wind Effects," *ASCE Journal of Structural Engineering*, Volume 114, Number 10, October 1988.

Twisdale, L. A., *et al.*, *Tornado Missile Simulation and Design Methodology*, EPRI NP-2005, Electric Power Research Institute, Palo Alto, California, August 1982.

Wen, Y. K., and Chu, S. L., "Tornado Risks and Design Windspeed," *Journal of the Structural Division*, ASCE, Volume 99, Number ST12, December 1973.

CONSEQUENCES OF PRESSURE BLAST

THE PROBABILITY OF FATALITY INSIDE BUILDINGS

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ESTC RISK ASSESSMENT STUDY
DISCUSSION PAPER

CONSEQUENCES OF PRESSURE BLAST: THE PROBABILITY OF FATALITY INSIDE BUILDINGS

Introduction.

1. The interest within UK(MOD) in Risk Assessment has been described elsewhere.* The method being developed for explosives storage within ESTC is based upon estimates for the risk of fatality for each of the prime hazards, blast, weapon fragments, building debris and thermal effects. There is reasonable agreement between different models which predict fatality from blast in the open air, but we have found some differences of opinion concerning various models for fatality inside domestic buildings, and an almost complete lack of data at ranges beyond Scaled Distance 10 ($m/Kg^{1/3}$ - equivalent to a peak side on pressure of approximately 0.15 bar).

2. Although the probability of fatality from pressure blast at these distances is likely to be low, it is difficult to dismiss it as negligible, and it could form a significant input into many risk assessment situations. This is especially true where ammunition storage areas adjoin residential districts, where the aggregate of many small individual risks could be expected on occasions to generate an unacceptable societal risk.

3. This paper briefly describes available information on the relationship between pressure blast and the probability of fatality for persons in UK domestic housing. Options for a credible relationship between probability of fatality and scaled distance are described, and a possible solution is offered for discussion.

Fatality at close range, (SD < 10 or pmax > 0.15 bar)

4. Those familiar with the safety features of the Quantity Distance system for limiting the consequences of unintended explosive events, will recall that the procedure is established to control the extent of damage, and for pressure blast effects this is directly related to a maximum permitted peak overpressure. The UK approach to Quantity Distances is described in ESTC's Leaflet Number 5 part 1 Appendix 4, which also contains a table of information on accidental explosions which occurred during storage or processing operations. The procedure ensures

* Dr Connor - This symposium

that the consequences of any explosive accident are limited to "acceptable damage". Whilst fatality and injury to persons is controlled by the system, the Quantity Distance rules give no numerical estimate of the probablility of fatality for a specified peak pressure or scaled distance value.

5. Many years ago, MOD established damage categories[1] and a study of information from World War II concluded[2] that no fatalities occurred unless the damage to houses was category A(demolished) or Category B(irretrievably damaged). In addition, a more recent comprehensive survey of accident data showed that maximum recorded distance for Category B damage to domestic housing is Scaled Distance 7[3] (0.25 bar).

6. However, it is recognised that the variation in nature and quality of buildings makes it impracticable to define damage categories with sufficient precision to eliminate doubt over borderline cases. Also care must be taken to avoid equating MOD category B damage with the word "severe", since severe damage has in the past been used to signify category c_B (repairable) damage[4] in addition to worse categories. Damage to buildings from Air Blast is also discussed in reference 5, but there are difficulties in interpreting the results in terms of conventional explosives and UK domestic housing. Those interested in going more deeply into this work will need to note that the implied relationship between Scaled Distance and Damage or Lethality ignores the influence of impulse and the duration of the blast wave[6], and tends to be a worst case prediction for any specified quantity of explosive.

7. A detailed review of blast casualty rules applicable to UK Houses was published some years ago[7] and provides useful if unofficial values for pressure thresholds and probability of death and injury from both nuclear and conventional explosive events. The report gives fatality data in different forms for various accidental and war-time explosions, but in Appendix 1 and figure 1 we have attempted to generate comparable figures all converted to scaled distance. Considering the nature of the information, the extent of agreement is quite good; but I would draw your attention to the absence of data below 1% probability.

8. The report discussed the data with regard to a nuclear scenario, but one of the conclusions was that the threshold for fatality in buildings was above 2.5 psi (0.18 bar or approximately Scaled Distance 9.0). This also provides a maximum value for shorter duration conventional explosives.

9. In search of further information, we have reviewed some

information on a civil manufacturing incident in East London at Silvertown on 19 January 1917. (Reference 1 page 27, and reference 3). I will return to the longer range data later on, but at this point it is sufficient to note that this was a heavily populated area, and that there were 73 recorded fatalities, most of which were within Scaled Distance 5 (0.42 bar). The limit of Category B damage was SD 6 (0.31 bar).

10. Two other large scale accidents were also examined. The underground accident at Fauld near Burton on Trent in 1944 killed 68 people but there were no fatalities beyond Scaled distance 6 (Table 1 serial 16 and reference 8). At Port Chicago in 1944, 320 people were killed, also with no fatalities beyond Scaled Distance 6.[9]

11. In all three of these major accidents, and at RNAD Bedenham where thankfully, there were[10] no fatalities, it was certain that significant numbers of people were exposed to the accidental pressure blast and survived their ordeal.

12. The conclusion drawn from the four accidents briefly mentioned in the preceding paragraphs is that lethality from blast falls rapidly with increasing distance, and that the figure of 2×10^{-3} at SD 8.7 deduced in reference 2 is consistent with estimates of 750 survivors at Silvertown, and 600 at Port Chicago between SD 6 and SD 11 (Table 2). There is therefore good reason to accept the relationship between Scaled Distance and Lethality suggested by figure 1 and extrapolation out to Scaled Distance 10 is justifiable on the basis of known accident information. (figure 2).

LETHALITY PROBABILITY AT LONG RANGE.

13. On the other hand, the current quantity distance relationship for inhabited buildings is also considered by many to present a significant, but unquantified risk of fatality. The IBD is at Scaled Distance 22 and is equivalent to 0.05 bar, well below the threshold value suggested by reference 7.

14. The linear extrapolation of the close range lethality data would lead one to believe that the risks of fatality from pressure blast at distances well within current Inhabited Building Distances would be trivial. However, the mathematical justification for extrapolation of probit relationships into the low probability tail regions is questionable. At SD 22, the figure suggested from linear extrapolation of figure 2 is about 10^{-7} per event. This does not entirely accord with current views of possible causes of death - glass breakage, distraction while

in a dangerous situation, involuntary movement, electrical faults and so on. It would appear that an entirely separate group of fatality mechanisms apply, which make an insignificant contribution to fatality probability at close range, but which dominate at longer range. The problem is how to obtain a credible numerical estimate for the risk involved at Scaled Distances between 10 and 50 (0.02 bar).

15. We can get an indication of the maximum value of risk involved at these distances, by estimating the probability of survival for populations present at the time of recorded explosions. Although the four incidents discussed in paragraphs 9-11 were very different, it is probable that the blast effects at long range were not dissimilar. It is therefore acceptable to add the populations exposed at each site within the same range of distances, since people from all four sites will be included in the set of people who have been exposed to one explosion at the specified scaled distance and survived.

16. The estimates of lethality in Table 2 are based upon the assumption that the next person to be exposed to the pressure blast at the specified distance will be killed, and each estimate therefore can be considered to be a maximum value. More involved methods can be used if the basic argument is accepted, but the results will probably not alter significantly. Various devices were used to estimate the exposed populations- these include:-

-Counting houses on large scale maps and multiplying by 4 for assumed occupancy-Population data quoted in Pears Cyclopedia for 1951 and 1961

-Estimating a small area from counting houses and using the area of ground they cover to generate a population density which can be applied to a much larger but similar built up area.

-Use of the known population per square kilometre for West Ham in 1917 from historical references and applying this to the outer areas surrounding Silvertown.

17. The figures are of course approximate, but should serve to provide order of magnitude probabilites of fatality, and could probably be improved considerably if this was considered worth while.

18. The only attempt to provide figures hitherto for long range fatality probability known to us, is reference 11, and these values are included in Figure 2. Although these figures

were extremely valuable when they were introduced, they are now recognised to be over cautious. The estimate for fatality at the Inhabited Building Distance (SD 22) was greater than the fatality probability given by the data recorded in reference 7 for SD 6.

19. The figures we have produced from survival data provide a significantly lower estimate of fatality probability at Scaled Distances between 10 and 50. At Scaled Distance 10 and below, the existing data from several sources fits a linear plot quite well. A combination of the linear short range data and the curved longer range estimate offers a compromise in between linear extrapolation of the close in data and reference 11. The resulting composite line cuts the unit probability line at SD 3.0 (1.2 bar) and range and provides a credible relationship between scaled distance and fatality probability over all scaled distances likely to be of interest out to the purple line (SD 44 or 0.025 bar) and beyond.

CONCLUSION

20. Although evidence for the relationship described in the previous paragraph is very limited, it offers a defensible compromise between less acceptable extremes, and is capable of being refined if more data can be brought to light. The relationship can be used to assess risks out to the purple line (SD 44).

APPEAL

21. It is highly likely that many of those reading this note will have access to accident data bases or information. I would be most grateful if those who find that thay have evidence for deaths inside buildings from the effects of pressure blast at metric Scaled Distances above 6 (or below 0.42 bar - or even under 5.9 psi) would take the time to put details on the questionnaire at figure 3, and to fax or mail me a copy. In return I would send a copy of the revised discussion note when available.

ACKNOWLEDGEMENT

22. In searching for data for this proposal, I have had a great deal of help from Dr K N Bascombe, and the secretary of the Newham Historical Society, Mr F Sainsbury. Mr L McKinley from ST(58) provided the Bedenham data which started the project off, and Major C J Phillips from the Risk Assessment Study has provided the analysis of Port Chicago and MOD Accident Data.

REFERENCES

1. Notes on the Basis of Outside Quantity Distances for Explosives involving the Risk of Mass Explosion. - Major F Healy 3/7/Explos/43 1965 Reprint. RAST 1311

2. The consequences of Blast Effects from explosions of Hazard Division 1.1 Materials with particular reference to the Eastriggs Depot of CAD Longtown. - Unpublished MOD Report - J C Todd Hunting Engineering TP28118/2 December 1986 RAST 1012

3. An Audit of Outside Quantity Distances for Open Stacks and Buildings containing mass exploding ammunition. Col F Cantrell RMCS Shrivenham D/R/11 April 1988. RAST 1056

4. Expected severity and variation of damage to Dwellings at the Outside Safety Distance. - R R Watson D/Safety/ A/82/5/8D -31 January 1969. RAST 1157

5. The Effects of Nuclear Weapons - S Glasstone and P J Dolan, Castle House Publications Ltd 1980 - ISBN 0 7194 00481

6. Explosion Hazards and Evaluation - W E Baker et al Elsevier 1983 - ISBN 0 444 42094 - 0 (Vol 5 in a series)

7. A Review of the Blast Casualty Rules Applicable to UK Houses. Dr S Hadjipavlou and Dr G Carr Hill. Home Office Publication 34/86. RAST 1096

8. Archive notes relating to the Explosion at Fauld, Burton on Trent. ESTC library number 171

9. The Port Chicago, California Ship Explosion of 17 July 1944. US Army Navy Explosives Board. Washington DC -Technical paper No 6 - (P 14718) ESTC Library No. 322 RAST 1368

10. Observations on the extent of damage caused by the Bedenham Explosion - E Garratt 20 October 1950 and Analysis of damage to civilian premises - Unpublished MOD Report - D P Lidstone 7/explos/59 enc 2 -17 Jan 1951. RAST 1308

11. Explosive Limits in Ports - Unpublished MOD Report - J Henderson D/Safety 9/1/8 September 1984 RAST 1309

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TABLE 1 - UK MILITARY EXPLOSIONS

FATALITY FROM PRESSURE BLAST - GREATEST DISTANCE TO FATALITY

A summary of the maximum distances from explosion sites at which fatalities have occurred which could have been caused by blast. (either directly or by blast induced building collapse.)

Explosion Site	Reference (see end)	NEQ Kg	Approx SD for farthest fatality
Rotherwas	1	136	4.8
Gravely	1	163	<1
Irvine	1	1016	<1
Offley	1	2358	9.4 [1]
Catterick	1	2720	<1
Soham	1	5216	1.1
Bootle	1	8482	3.2
Gascoigne Wd	1	12250	5.9 [2]
Janas B Abs5	1	12700	<1
Igloo Mag	1	15400	<1
Janas B Abs9	1	16260	<1
Janas B Abs10	1	268K	<1
Janas B Abs7	1	363K	<1
Anes B Abs2	1	499K	2.5
Anes B Anes1	1	1724K	<1

continued overleaf

TABLE 1 (CONTd)

Burton-on-Trt	1	2423K	5.7 [3]
ECP Ltd	2	1800	<1 [4]
Bishopton	2	1700	1.4 [4]
Bishopton	2	1600	<1 [4]
Bishopton	2	1550	<1 [4]
Stevenston	2	820	1.4 [4]
Bridgwater	2	450	1.3 [4]
Ardeer	2	210	8.4 [4]
Rainbow Ltd	2	45	28 [4]
AWRE	2	23	23? [4]

Notes for Table 1:

[1]. The fatalities were passengers in a bus which moved contrary to instructions. Hence it is possible that blast was not a primary contributor to the fatalities.

[2]. No detailed records found for this accident.

[3]. Fatalities at this distance were variously due to drowning, missiles and building collapse.

[4]. Fatal manufacturing accidents which tend to involve quantities of explosive below 2000Kg, frequently involving disintegration of plant and process buildings. These details are shown for completeness, but are not considered relevant to the estimation of lethality from blast at explosives storehouses since:

(a) Not under MOD control.
(b) More operators involved in close proximity.
(c) Major risk from fragments.

References for Table 1:

1. Notes on the basis of Outside Safety Distances for explosives involving the risk of mass explosion. 3/7/Explos/43 March 1959. Table 1.

2. ESTC Leaflet Number 5 Part 1 Appendix 4.

TABLE 1

PRESSURE BLAST LETHALITY ESTIMATES FROM EXPOSED SURVIVORS AT DIFFERENT SCALED DISTANCES

Min SD	0	6	11	22	44	88
Max SD	6	11	22	44	88	176
SILVERTOWN						
[1]	73	0+	0	0	0	0
[2]	~320	750	2800	31300	215000	910000
50,000Kg 19/1/1917						
PORT CHICAGO						
[1]	320	0	0	0	0	0
[2]	327	600	1000	640	9400	58000
1,710,000Kg 17/4/1944						
FAULD						
[1]	68	0	0	0	0	0
[2]	~120	400	?*	?*	59000	177000
2,272,000Kg 27/11/1944						
BEDENHAM						
[1]	0	0	0	0	0	0
[2]	(0)	(0)	(0)	1700	26500	160000
36,000Kg 14/7/1950						
Estimated probability		5×10^{-3}	2.5×10^{-4}	3×10^{-5}	3×10^{-6}	7×10^{-7}

Notes:
[1] deaths [2] estimated number exposed * less than 3000
+ Fatalities at this distance are not recorded but could have been caused by flying debris.

FIGURE 1

BLAST LETHALITY DATA (CLOSE RANGE)

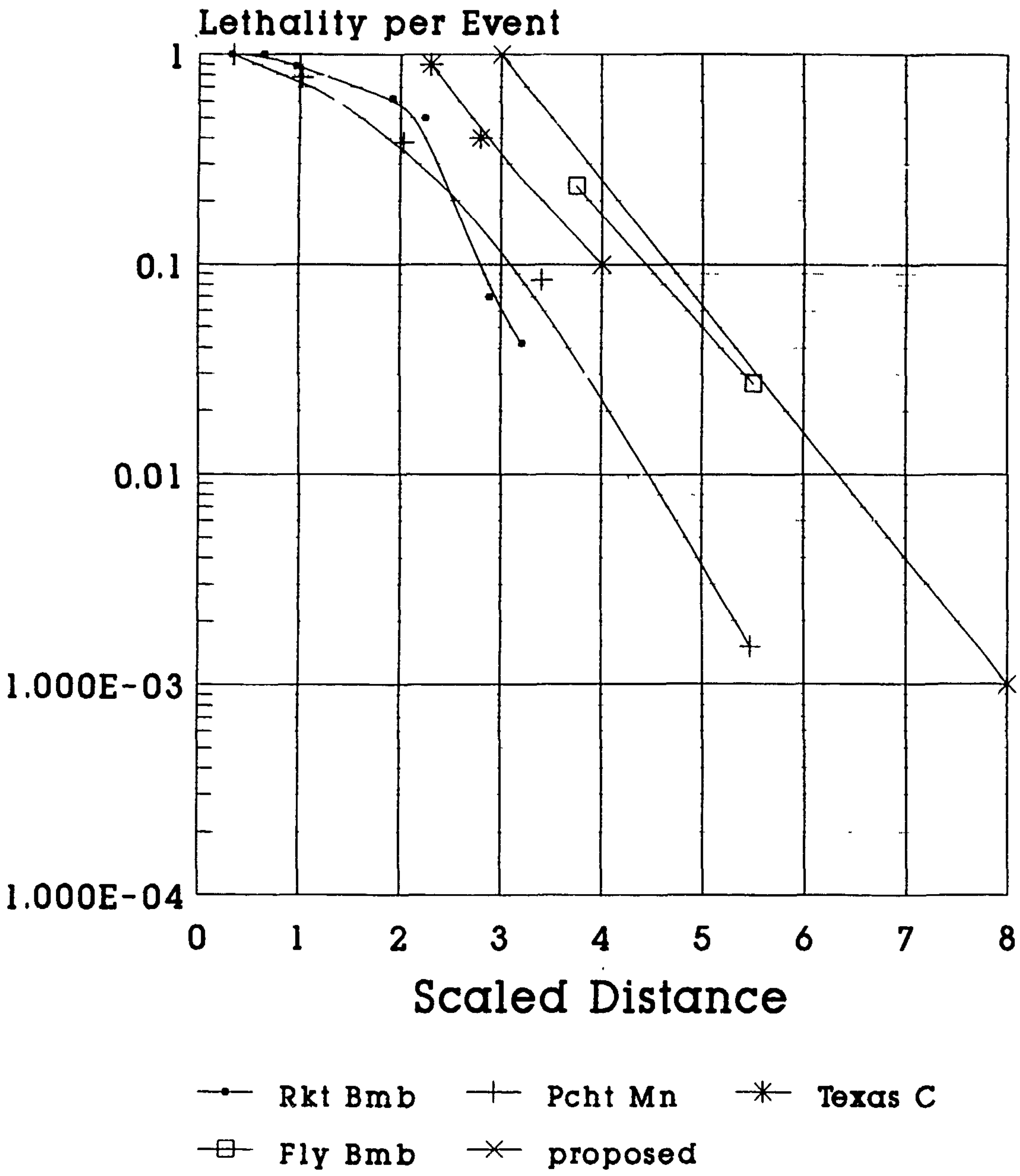

FIGURE 2

BLAST LETHALITY PROBABILITY FROM SURVIVOR/FATALITY RATIO

COMPARISON OF RELATIONSHIPS

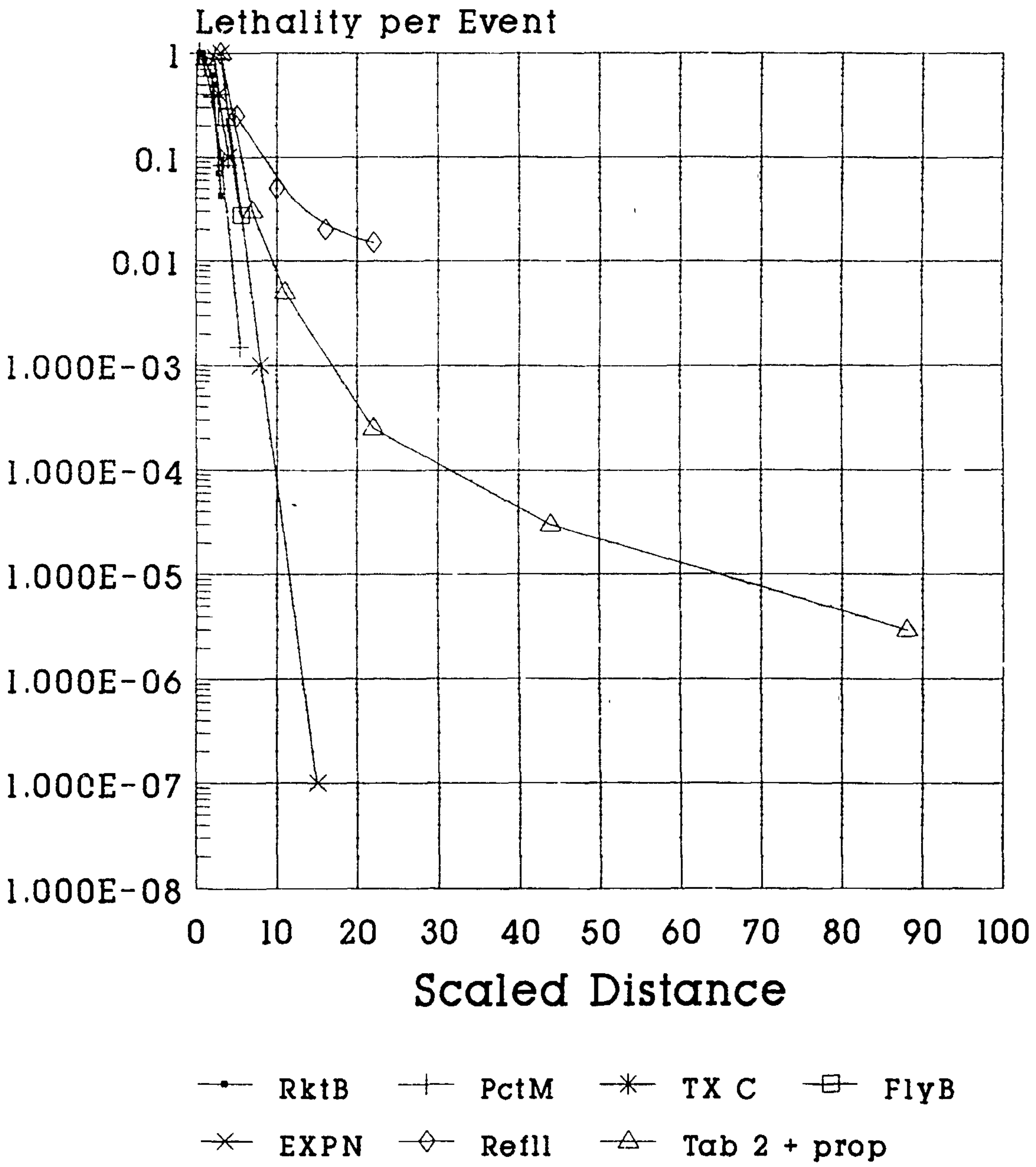

FIGURE 3

QUESTIONNAIRE - ACCIDENT DATA

Please fax reply to:-
Dr D Hewkin, Room 2006 ESTC(RAST) on - UK(0)81-381-9992
or mail to the above at:-
Empress State Building, Lillie Road, LONDON SW6 1TR

From:- name:- telephone:-

address:- fax:-

PERSONS EXPOSED TO PRESSURE BLAST FOLLOWING AN EXPLOSIVES ACCIDENT

Accident Date:- Place:-

Report Reference:- NEQ:-

NUMBER		MAX DISTANCE		TYPE	NOTES
EXPOSED	DEAD	METRES	FEET		

TYPE A PRIMARY BLAST
TYPE B TRANSLATION OF BODY
TYPE C INSIDE COLLAPSED BUILDING
TYPE D STRUCK BY FLYING DEBRIS
TYPE E OTHER - PLEASE SPECIFY

additional comments:-

Appendix 1

CONVERSION OF DATA TO SCALED DISTANCE

1. TEXAS CITY

Data Source: Reference 7 figure 6.3.1

% fatality	psi	bar	Metric Scaled Distance*
90	30	2.1	2.3
40	20	1.42	2.8
10	9	0.64	4.0
Threshold	2.5	0.18	8.5

* Conversion via NATO Manual AC258 D258 Part II Figure 7 - III

2. PARACHUTE MINES

Data Source: Reference 7 table 6.5.6 (Store NEQ 725 Kg)

number exposed	fatalities	%	max distance (feet)	SD
4	4	100	10	0.34
19	14	(73)	20	
14	11	78	30	1.02
14	5	(28)	40	
18	5	(36)	50	
26	10	38	60	2.03
31	1	(3)	70	
17	1	(6)	80	
31	2	(6)	90	
59	5	8.4	100	3.4
141	0		125	
151	0		150	
157	0		175	
184	0		200#	5.47

The number of persons exposed between 100 and 200 feet was 633, and there were no fatalities. This suggests a maximum value for probability of fatality at 200 feet of 1.5×10^{-3}.

3. ROCKET BOMBS

Data Source: Reference 7 Table 6.5.6. (Store NEQ = 850Kg)

number exposed	fatalities	%	max distance (feet)	SD
7	7	100	10	0.32
7	7	100	20	0.64
8	7	88	30	0.96
23	12	(52)	40	
31	19	(61)	50	
37	23	62	60	1.92
42	21	50	70	2.24
32	5	16	80	
42	3	7	90	2.89
72	3	4.2	100	3.21
127	5	3.9	125	4.01
173	0		150	
224	0		175	
274	0		200*	5.76

* The number of persons exposed between 125 and 200 feet was 671, and there were no fatalities. This suggests a maximum value for probability of fatality at 200 feet of 1.5×10^{-3}.

4. FLYING BOMBS

Data Source: Ref 7 Table 6.5.1 (R_B values from ref 1)

% fatality	damage category	R_B	SD
23.5	A	0.675	3.75
2.7	B	1.0	5.56
0#	C_B	1.74	9.67

The number of persons exposed to C_B damage was 326. This suggests a maximum value for the probability of fatality at Scaled Distance 9.67 of 3×10^{-3}.

U.S. ARMY CHEMICAL MATERIEL
DESTRUCTION AGENCY
(USACMDA)

THE ROLE OF RISK ANALYSIS IN DIRECTING THE QUALITY ASSURANCE PROGRAM OF THE U.S. ARMY CHEMICAL MATERIEL DESTRUCTION AGENCY

Presented at the:

Twenty-Fifth DOD Explosive Safety Seminar
18-20 August, 1992
Anaheim Hilton Hotel, Anaheim, California

Specialized Session
Chemical Explosive Disposal

Prepared and Presented By:

Thomas Kartachak
Risk and Surety Management Division, USACMDA

and

John Jardine
Science Applications International Corporation

THE ROLE OF RISK ANALYSES IN DIRECTING THE QUALITY ASSURANCE PROGRAM OF THE U.S. ARMY CHEMICAL MATERIEL DESTRUCTION AGENCY

Abstract

U.S. Public Law 99-145 authorizes the demilitarization of chemical agents and munitions in the custody of the United States of America and requires that demilitarization be carried out with maximum consideration for the safety of the public, the worker and protection of the environment. More recent supplemental laws further define the goals of the demilitarization effort in terms of being able to "demonstrate the quality" of demilitarization efforts. The U.S Army Chemical Materiel Destruction Agency (USACMDA) is responsible for providing centralized intensive management of the life cycle of the demilitarization and disposal of both the U.S. stockpile of lethal chemical warfare agents and munitions and disposal of those agents, munitions and facilities considered to be non stockpile. The degree of difficulty inherent to chemical demilitarization and the scope of the demilitarization program require the use of rigorous techniques that focus and enhance decision making and planning efforts. Risk analyses is one of several means by which the USACMDA enhances the decision making process.

The USACMDA employs risk analyses and its resulting expressions of probability and consequence as means of targeting quality assurance efforts in the chemical demilitarization program. Where probability and consequence combine to indicate undesirable results, the USACMDA reduces the probability of undesirable results through the implementation of a comprehensive quality assurance program. The USACMDA employs risk analyses as a basis for targeting quality assurance efforts not only where environmental protection, safety of the public and worker are concerned but also in the area of operational reliability.

Background

In 1986 U.S. Public Law 99-145 mandated the destruction of the unitary U.S. chemical weapons stockpile. Pursuant to law, the U.S. Army formed the Office of the Program Manager for Chemical Demilitarization (PM Cml Demil) to identify, initiate and manage the efforts necessary to destroy the unitary chemical weapons stockpile. Supplemental laws and Department of Defense directives have more recently included all U.S. Department of Defense chemical warfare destruction activities (stockpile and non-stockpile) within the scope of the U S. Army's chemical materiel destruction program. To meet this challenge, the Secretary of the Army has established the U.S Army Chemical Materiel Destruction Agency (USACMDA) which now includes the PM Cml Demil and the newly formed Office of the Program Manager for Non-Stockpile Chemical Materiel (PM NSCM).

The scope of the USACMDA mission is considerable. The destruction of the unitary chemical weapons stockpile alone involves the design, construction, systemization, operation and decommissioning of eight planned disposal plants within the continental United States and one full scale prototypical plant on Johnston Atoll. Although it is currently being studied, the scope of the non-stockpile destruction program (which includes the destruction of binary munitions, old production facilities and chemical wastes) may well be as broad as the stockpile program in terms of overall effort. The scope and degree of difficulty inherent to chemical warfare destruction activities, the active interest of the public and Federal agencies and, the requirements of Public Law require the use of rigorous techniques that focus and enhance the decision making process within USACMDA. Quality assurance and risk analysis are two techniques that play an important role in this regard.

The Paradox of the Chicken and the Egg

Figures 1 and 2 provide an overview of how the quality assurance program and risk analysis program are structured within USACMDA. It is important to note that Figure 1 (Quality Assurance Program Overview) illustrates the framework within which a technical task, such as risk analysis, is accomplished. Within USACMDA quality assurance is not the objective, it is, however, the means by which confidence in the end result is inspired, encouraged and ultimately demonstrated. At the outset of the disposal program it is essential that the quality assurance program be established before technical tasks begin. This order of precedence may appear to be a paradox often expressed by the question, "Which comes first, the chicken or the egg (i.e., technical tasks or the quality assurance program)?". It may appear illogical to put a quality assurance program into effect without knowing precisely "what" items and activities are important enough to warrant the program but, at the outset of a program it is imperative that confidence in the quality of even the first technical task be beyond reproach. Afterall, the second and third technical tasks are ordinarily based on the results produced by the first technical task. If the quality of work produced in the first

technical task is questionable, all subsequent efforts based on these results will also be questioned. In this sense, the paradox of the chicken and the egg is irrelevant. There is no chicken and there is no egg. There is, however, a need to assure the quality of technical work.

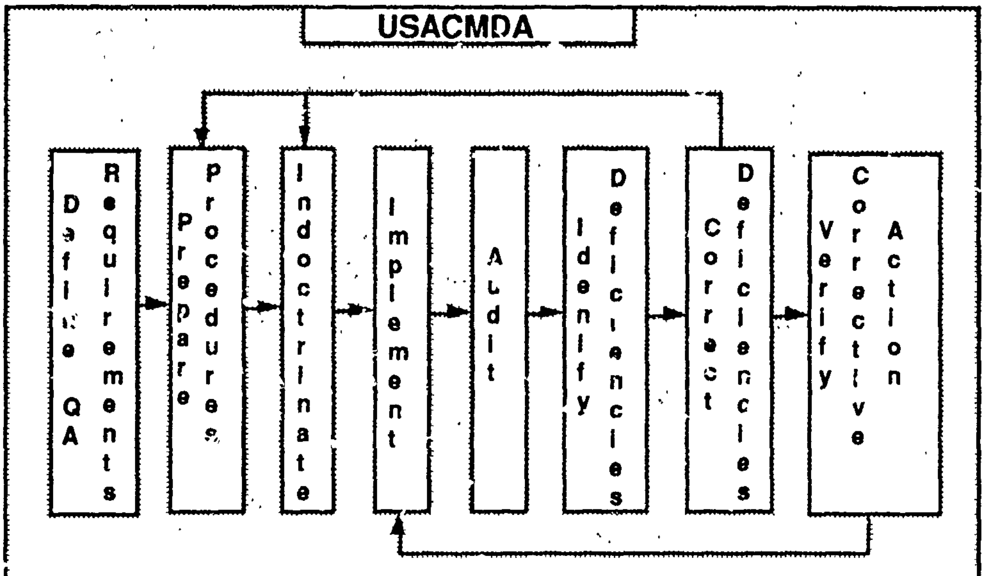

Figure 1. Quality Assurance Program Overview

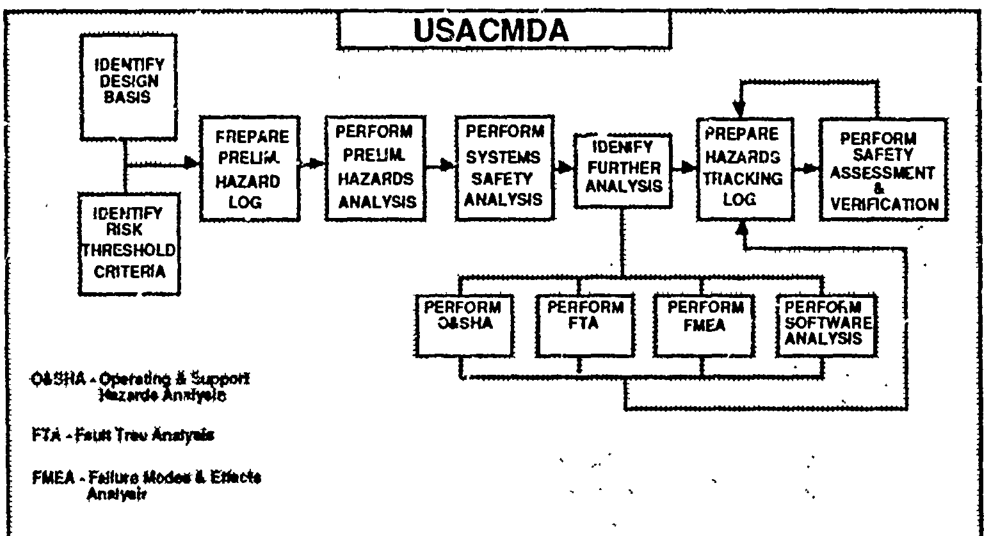

Figure 2. Risk Analysis Program Overview

This principle is at work at the outset of early USACMDA design phases such that confidence in each building block of the program is attained. As the technical work evolves to a point where sufficient information is available to separate the set of important items and activities from the simply necessary items and activities, a transition must be made from applying quality assurance to "whole" efforts (such as design and risk analysis) to focusing quality assurance efforts on specific items and activities. As in other programs of similar scope and degree of difficulty, this point of transition occurs within USACMDA following the completion of the first generation of risk analysis for a particular disposal site. Prior to having completed risk analysis the information upon which decisions regarding importance can be based is simply not available. Figure 3 illustrates the natural phases involved in the evolution of defining quality assurance measures for a USACMDA disposal site and how risk analysis plays an central role in this evolution.

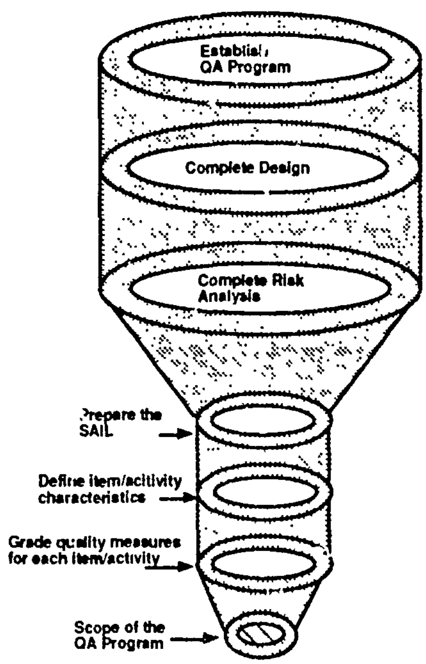

Figure 3. Phases of QA Program Evolution

The Role of Risk Analysis in Defining the Scope and Direction of the Quality Assurance Program

Once progress is made beyond the early phases of design, risk analysis becomes the principal means by which USACMDA defines the scope and direction of the quality assurance program. The application of the USACMDA quality assurance program is reserved for those items and activities whose probability and consequence of failure or malfunction exceeds safety and environmental compliance threshold criteria (see Figure 4). Once risk analysis has established the probabilities and consequences for each item and activity appearing in a given design, these results are compared to the threshold criteria and the set of items and activities that have the greatest degree of influence on the ability of USACMA to successfully achieve the objectives outlined by Public Law begins to form. Within USACMDA, this set of items and activities are

USACMDA

An item or activity will be placed on the SAIL if:

1. **Its single failure can cause a migration of chemical agent in an amount that would exceed Permissible Exposure Limits (PEL).**
2. **Its single failure can cause death, illness, or any manner of worker disability.**
3. **Its single failure can cause an agent release of any kind, or a non-agent emissions release that exceeds allowable limits or conditions prescribed in regulatory permits and commitments.**
4. **Its sole purpose is to provide redundancy for an item or activity that qualifies for inclusion on the SAIL as a result of the application of Criteria 1 through 3 above.**

Figure 4. SAIL Threshold Criteria

compiled into a list known as the "Significant Items and Activities List" or SAIL. Following completion of the SAIL, USACMDA characterizes each item and activity listed on the SAIL with respect to their commercial grade status, complexity, quality history, the degree of coverage by applicable national codes and standards, the need for in-process controls and, the need for special shipping and handling measures. The combination of importance (significance) and characteristics for each item and activity serves as a basis from which USACMDA selects the set of quality assurance measures that are essential to the inspiration and demonstration of confidence in their quality. The process of selecting quality assurance measures based on the combination of importance and characteristics is known as "Grading".

Sharpening the Focus of the Quality Assurance Program Through Grading

Figure 5 illustrates the topics addressed in the USACMDA Quality Assurance Program Plan (the QAPP). The QAPP is both the policy statement and the standard of expectations for the USACMDA quality assurance program. Chapter One explains the concept of the SAIL and Grading under the title Quality Program Planning and Assessment. The remaining portions of Chapter One and the remaining Chapters (Two through Thirteen) represent, in effect, a menu of quality assurance measures that are proven to enhance confidence in the quality of technical work. Not all quality assurance measures described in the QAPP are applicable to all items or activities that appear on a SAIL. Grading, or the "fitting" of quality assurance measures with

USACMDA

Chapter	Topic
1	Quality Program Planning & Assessment
2	Document Control
3	Design Control
4	Computer Software Control
5	Procurement Control
6	Inspection and Testing
7	Control of Materials, Items and Data
8	Mfg., Construction, Maintenance and Operations Control
9	Measuring and Test Equipment Control
10	Handling, Storage and Shipping
11	Control of Nonconformances
12	Control of Records
13	Audits and Surveillance

Figure 5. Topics Addressed by the USACMDA QAPP

each item or activity on a SAIL, is the process by which the optimum set of applicable quality assurance measures are determined according to importance and characteristics. To improve uniformity of the selection on the first grading attempt, USACMDA has prepared a logic diagram and computer code that provides a "baseline" set of quality assurance measures for each possible combination of importance and characteristics. This "baseline set" is then sent through a review process to confirm applicability and comprehensiveness. Figure 6 illustrates a portion of the computer logic for grading items that are important to safety. While grading has merit in terms of sharpening the focus of the USACMDA quality assurance program, Figure 7 illustrates that the value of grading is limited in comparison to that of risk

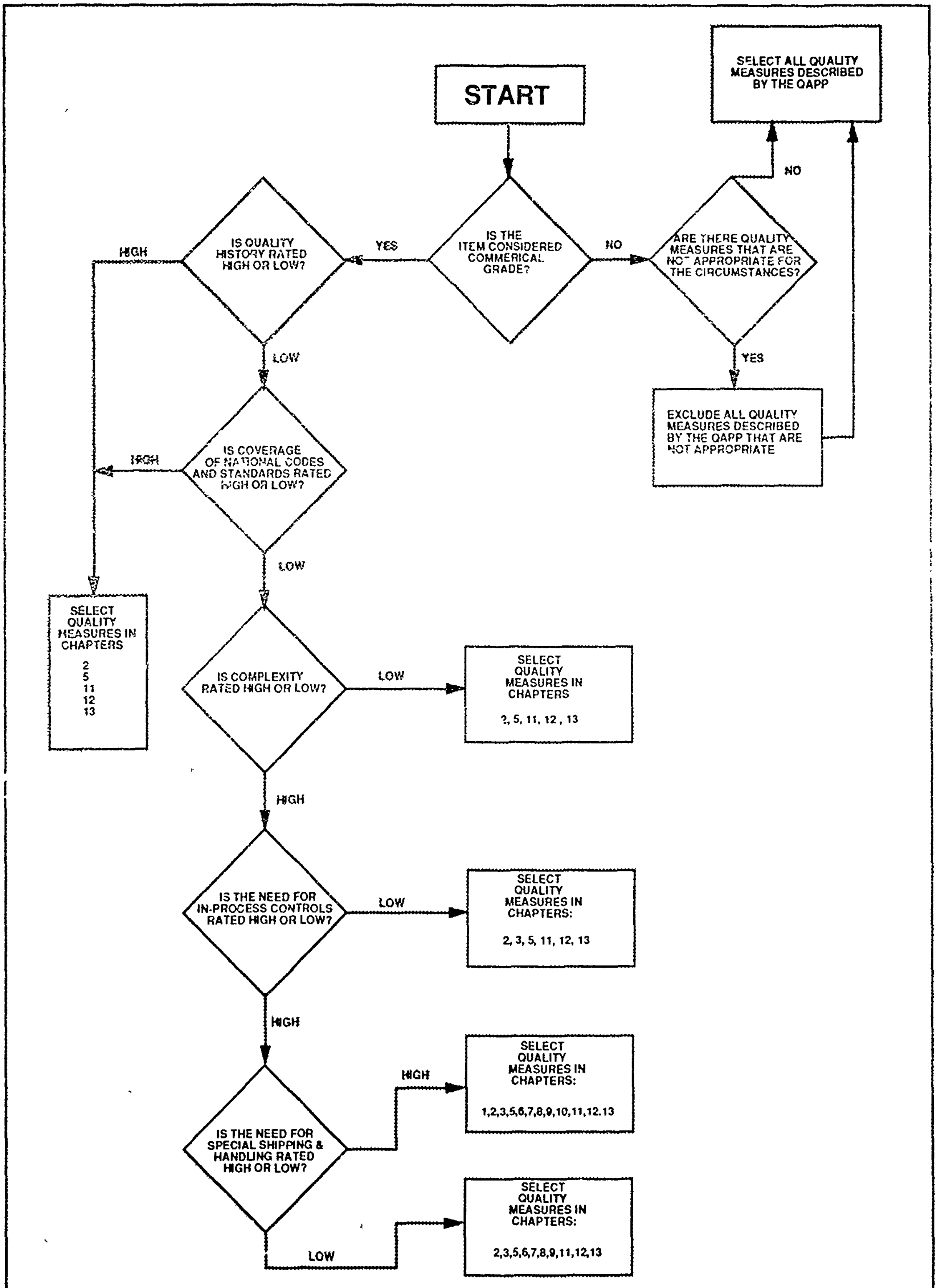

Figure 6. Computer Logic for Grading Significant Items

analysis. It should be noted in Figure 7 that an improvement in the grading process is heavily dependant on the extent, currency and comprehensiveness of risk analysis.

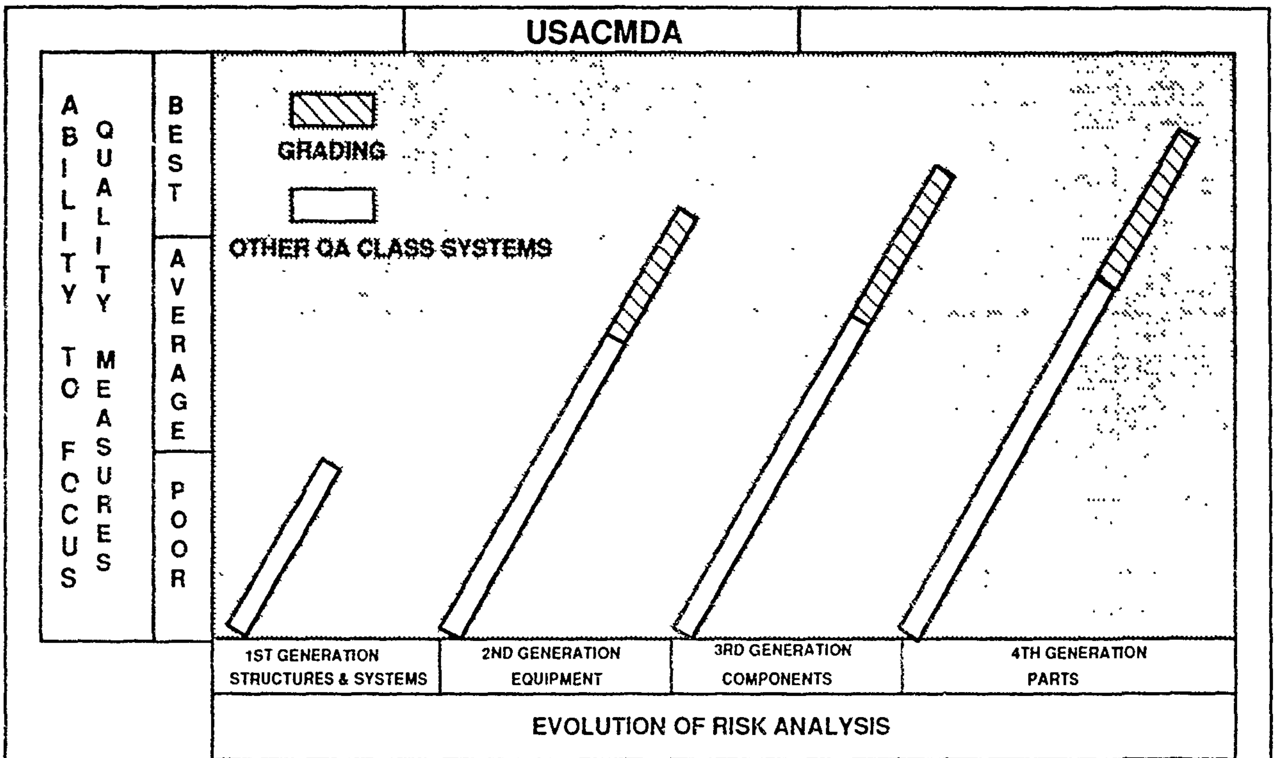

Figure 7. The Effect of Risk Analysis Evolution on the Ability to Focus Quality Assurance

Summary

The scope, degree of difficulty, active public and federal interest and, the requirements of public law demand the use of rigorous techniques that focus and enhance the decision making process within USACMDA. USACMDA employs quality assurance and risk analysis in a complimentary fashion as means of enhancing confidence in the quality of the technical work. At the outset of design activities the quality assurance program is applied in "whole" fashion until sufficient information exists to permit the definition of the set of items and activities that exhibit the greatest degree of influence on the ability of USCMDA to achieve the objectives outlined by Public Law. When sufficient information is available, risk analysis serves to define the set of items and activities that are important to safety and environmental compliance. While the grading process is used by USACMDA to "fit" important items and activities with the optimum set of quality assurance measures, it is risk analysis that contributes most to the definition of the scope and direction of the quality assurance program.

CHEMICAL WARFARE MATERIAL AT FORMERLY USED DEFENSE SITES

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1. INTRODUCTION

This paper highlights cleanup efforts under the Defense Environmental Restoration Program at sites contaminated or suspected to be contaminated with chemical warfare materiel. Chemical warfare materiel are munitions or containers holding blister agents, nerve agents, blood agents, and choking agents. Also of concern are soil and scrap contaminated with these agents, or soil contaminated with decontaminating solutions. This paper outlines the history of military use that led to contamination. It also provides an outline of Response Actions including the detailed planning assessment and facilities necessary to support a cleanup.

2. **BACKGROUND**

2.1 LETHAL CHEMICAL AGENTS

As defined by the U.S. Army lethal chemical agents are those agents that primarily cause death among target personnel. They are limited to choking, nerve, and blood agents.

2.1.1 Choking agents injure an unprotected person primarily in the respiratory tract. They attack the membranes of the nose, throat, and lungs causing swelling. The lungs fill with fluid and death result from lack of oxygen or "dryland drowning". The most common choking agent is Phosgene or (CG). CG is a non-persistent colorless gas that although is of limited solubility in water, decomposes immediately in most field conditions. Used extensively in World War I, CG accounted for more than 80% of the chemical agent fatalities in that war.

2.1.2 Nerve agents inhibit the enzyme acetylcholinesterase which is required for the function of many of the bodies nerves and muscles. The type of attack on the body is dependent on both the dosage and the route of exposure. However, nerve agent may cause the cessation of functioning of skeletal muscles (arms, fingers, etc.), involuntary muscles (heart, lungs), and the central nervous system. The principle nerve agents are of the G-agent and V-agent varieties. G-agents are fluorine or cyanide containing organophosphates. They are a colorless liquid and very non-persistent. G-agents, although a liquid are extremely volatile and have a vapor pressure so high that vapors are lethal. V-agents are sulfur containing organophosphorous compounds. They are a highly persistent, extremely toxic, oily liquid. Human effects of both V and G series nerve agents are primarily the same.

2.1.3 Blood agents are cyanide containing compounds whose primary route of entry into the body is through inhalation. Blood agents prevent cell respiration and the normal transfer of oxygen from the blood to body tissues. The most common blood agents are hydrogen cyanide (AC) and cyanogen chloride (CK). Both are highly volatile and very non-persistent.

2.2 BLISTER AGENTS (VESICANTS)

Although blister agents do cause fatalities, blister agents were also intended for use to restrict the use of terrain, to slow movements, and to hamper the use of materiel and installations. All blister agents are persistent and may be employed in the form of colorless gases and liquids. They damage any tissue that they contact. They affect the eyes, lungs and the skin. They may cause lethalities, primarily through inhalation, but skin damage is their main casualty producing effect. Blister agents, in addition to their designed effects are a long term health hazard because they are known carcinogens.

2.2.1 Mustards are the most common grouping of blister agents. Mustards are divided into two types, sulfur mustards (H and HD) and nitrogen mustards (HN-1, HN-2 and HN-3). During World War I mustard (H) was the only blister agent in major use.

2.2.2 Arsenical vesicants are a group of related compounds in which arsenic is the central atom. The main arsenical vesicants are lewisite (L), mustard-lewisite mixture (HL), and phenyldichloroarsine (PD). Lewisite is the most common and the only one to be addressed in this paper. It produces similar effects as mustard with the exception is that L produces immediate pain.

3. HISTORICAL MEANS OF CONTAMINATION

3.1 GENERAL. The United States is very different from other parts of the world as to the means by which chemical warfare materiel is contaminating the earth and posing a threat to man and the environment. Unlike Europe, Africa, and the Middle East, no battles were fought in the U.S. using chemical agents. Even today, dud fired rounds are found in Europe still containing their chemical payloads. These munitions are left over from World War I battles. In other places, chemical rounds are found from the World War II era. Although not fired in battle they are the results of either battle damage or the intentional destruction techniques used either by the conquering army or by the defenders to prevent the capture of materiels that could be used by the enemy. The contamination in the U.S. is the direct result of the lack of knowledge of environmental effects and the vastness of the country lending to the philosophy that some areas could be contaminated forever and no one would be affected. The thought at the time seems to be that of taking immediate danger to the individual away, thus making burial a common solution to the immediate problem. No thought seems to have been given to the long term effects that these practices wrought.

3.2 Manufacturing and storage were two of the primary initial causes of contamination. In the manufacturing process, some of the techniques used contributed directly to contamination. For instance waste water settling ponds that were covered over or allowed to dry up, today contaminate both soil and ground water with high levels of arsenic used as the base in lewisite manufacturing. Dumping and burying of defective batches was a usual practice. The water and decontaminating solutions used to clean production lines went down drains and was not always collected. In the loading plant both leaking bulk containers and leaking munitions often had their contents dumped in pits dug into the earth, lime was then added and the pit covered. The same is true in storage operations. It would seem that many of the bulk containers and munitions in storage developed leaks because of the reactivity of the chemical agent to metal. Again dumping into a pit with lime was often the solution. Years after manufacturing ceased, the walls of building were found to be permeated with chemical agents, particularly blister agents.

3.3 Disposal operations following World War II contributed the greatest actual amount of contamination. The disposal activities, while involving the greatest volume, were carried out in more controlled situations. They were done on military installation and were done by various methods, approved at the time as safe. Some were, as discussed above, simply opening the munition or container, dumping the agent into a pit and adding some type of decontaminating solution. Finally the pit was covered and a new pit was dug.

3.3.1 In some cases, transfer operations took place such as transferring chemical agent from the munition to a bulk container like the one ton container. Two specific goals drove these operations. The first was the further use of the chemical agent such as the study of captured German nerve agent. Also agents were taken from either obsolete or inefficient munitions and later put in updated configurations. Finally, some chemical agents with industrial uses, such as phosgene, were sold to industry as a basis for fertilizer. The second was the recovery of the metal in the containers and munitions. This appears to be the paramount issue. Studies of many of the old reports of disposal operations detail only sketchy accounts of the disposal of chemical munitions but go into great detail about the amount and sometimes the condition of the metal salvaged.

3.3.2 The method to insure recovered metals were decontaminated was simply burning. Either in the smelting process or after the initial treatment of the chemical agent. This later was done by open burning. Some agent filled

containers were also vented by various methods (mechanical puncture, explosive puncture, or by being shot with a bullet) and open burned. This procedure involved digging a trench, filling the bottom of the trench with flammable materials such as wood to a depth of several feet, placing the munition or container on the flammable material, pouring diesel fuel over the entire trench and igniting. In most cases this was the most effective and left the fewest traces of contamination.

3.3.3 Burial was also an accepted method of disposal. It is not sure whether in some cases this was a sanctioned method or the result of a long day with a desire to take short cuts. Both are probably the case. As human nature would tend to verify the later, old Field Manuals refer to burial as a method of temporary storage. With changes in missions and transfer of personnel, it is likely that these temporary storage points were often forgotten.

3.4 Of all the contamination generating activities, the most frequently arising is in the area of movements. While many leaking munitions and containers were resealed or drained of their contents, which were placed in new and intact containers, many records and reports indicate this was not always the case. Many times the transport crews emptied the chemical warfare agents into pits dug along railroad tracks, dropped the agent container into the pit, threw in lime, and covered the hole over during a rail move. During port operations, bombs and containers were often taken out to sea and dumped. It may have been the intent to return at a future date and remediate or at least check the area, but records show this was done in only a small percentage of cases.

3.4.1 At Enclosure 1 is a typical report of a rail movement incident involving leaking 55 gallon drums. It details the response from the "Guard and Security Division of the Chemical Warfare Center at Edgewood Arsenal, Maryland. This report typifies the kinds of incidents that occurred over an approximate twenty year time frame of chemical warfare agent movements from the early 1940s to the early 1960s. In this case, using this report as a starting point, the Kansas City District of the Corps of Engineers has been able to locate this pit for future testing.

3.4.2 Enclosure 2 is an example of an attempt to investigate a suspect burial pit during a base closure operation. This is the basis for the expanding chemical warfare agent portion of the Huntsville Division of the Corps of Engineers, Design Center and Mandatory Center of Expertise, Ordnance and Explosive Waste five year work plan.

3.4.3 Enclosure 3 are examples of excerpts from typical water transport operations. In some cases, sea dumping was the final destination. In other cases, land burial was done. As is indicated, some of these operation were not totally successful.

3.5 One of the most complex and nagging problems today when dealing with chemical warfare materiel is the "War Gas Identification Set, Detonation, M1 and AN-M1A1," the "War Gas Identification Set, Instructional, and the "M1 Set, Gas, Toxic, M1 and M2". There are three reasons for why these sets create so many problems.

3.5.1 First there are many individuals in both civilian and military aspects of environmental remediation who are under the false belief that these are all diluted "sniff" sets used to familiarize the soldier in what different warfare agents smell like. There are indeed "sniff" sets that were used for this purpose. However there were also sets containing not only "neat" mustard but also a set containing GB nerve agent. Also some sets had Lewisite, a known carcinogen.

3.5.2 The second reason these sets are such a problem is that they were not accounted for. Records indicate how many sets went to what installations. But no records can be found to show what happened to the sets after they arrived at that installation. Because of the amounts of isolated incidents reported over the years from all parts of the country, it appears that a great many of these sets were not expended in training but were simply buried.

3.5.3 The third major problem with these sets is that the basic component is a glass vial. Unlike steel rounds of ordnance, bulk containers, or drums. Glass vials are extremely difficult to locate in the ground. Obviously, magnetometers and metal detectors won't locate glass. Currently being looked at for this purpose is Ground Penetrating Radar. However, this is not yet a proven method. It may be asked "Why bother to look? Glass is not contaminating the earth and the agent isn't leaking." This is true until you realize that these sets are being unearthed either during other Hazardous and Toxic Waste investigation or they are discovered by individuals doing other intrusive work such as installing a fence.

4.0 RESPONSE BY THE ARMY TO RECENT INCIDENTS

4.1 The Former Raritan Arsenal Site along with Former Ft. Segarra in the U.S. Virgin Islands are the politically sensitive issues that caused the U.S. Army to relook the methods of handling non-stockpile and abandoned chemical warfare materiels and to cause the Vice Chief of Staff of the Army on 1 June 1992 to publish policy guidelines in the form of a memorandum to The Assistant Secretary of the Army For Installations, Logistics, and Environment (ASA,ILE), The Commander, U.S. Army Materiel Command, and to The Chief of Engineers. This policy guidance (Enclosure 4) Subject: Restoration of Formerly Used Defense Sites (FUDS) Contaminated with Suspect Chemical Weapons (CW) Materiel, clearly delineates not only the priorities which the Army Staff places on its FUDS remediation, but also individual agency responsibility. It also proscribes funding to be used and breaks down what funds will be expended and where.

4.1.1 The established priorities for FUDS remediation as stated by The Vice Chief of Staff of the Army are Former Raritan Arsenal and Former Ft. Segarra. This is due primarily to the "High level public and governmental attention".

4.1.2 In setting down agency responsibility, the Vice Chief of Staff's Memo states, "The restoration of Raritan Arsenal and Fort Segarra will be carried out under the ASA(ILE) policy guidance. USACE retains on-site management responsibility. Director Space and Special Weapons, DCSOPS will be focal point for integration of chemical surety, safety, and security policy as it applies to this unique operation." In addition the roles and missions of the U.S. Army Chemical Materiel Destruction Agency (USACMDA), Corps of Engineers, and Army Materiel Command are defined.

4.1.3 Although when published, this memorandum was directed at off site movement and storage and not at other alternatives such as on site disposal, the funding requirements are either adequate or can be slightly shifted to be equitable. The memorandum states, "Funding requirements directly attributable to planning, preparation, and execution of restoration and recovery operations will be resourced from Defense Environmental Restoration Program (DERP) funding. Technical Escort Unit support to USACMDA will be on a reimbursable basis. Storage costs will be executed from AMC normal operating accounts."

4.2 In the past the Technical Escort Unit (TEU) has been the sole source of response to chemical warfare materiels (CWM) found either on military installations or on Formerly Used Defense Sites (FUDS). Although the Army has a program in place, the

Chemical Accident or Incident Response and Assistance (CAIRA) Operations were designed for accidents or incidents involving stock pile weapons and containers. Even if these events were to occur off installation, the gearing of the response is to transport of stock pile ordnance.

4.2.1 Recovered or discovered ordnance containing CWM has been the mission of TEU. If ordnance were found either on or off installation, the most common scenario was the closest Army Explosive Ordnance Disposal (EOD) unit was notified. After an inspection by the EOD team, if a CWM munition was suspected, the EOD team would either report the item directly to TEU or would follow the procedures in AR 50-6 which is to report the incident to the Army Operations Center who in turn makes notification through channels to TEU.

4.2.2 A reluctance on the part of EOD to notify TEU was soon formed because the same regulation that explained how to report a found munition also required whoever found it to secure it until relieved by proper authority. The TEU often took time to arrange aircraft, packaging materiel, protective clothing, and personnel transportation. Thus, the individual possessing the ordnance was duty bound to guard it, sometimes for several days.

4.2.3 Upon arrival at the site, TEU would take non intrusive samples (vapor samples), decontaminate if necessary, package and transport to the closest compatible Chemical Surety Storage Facility. This trip was by military aircraft, aircraft and crew, plus TEU personnel were certified under the provisions of AR 50-6. Under section 5.1, Legal Changes, this paper, the reasons for this process being no longer an option will be discussed. Here however, I will say that legal and public opinions have changed in many places making this type of operation less than desirable.

4.3 The U.S. Army Armament, Munitions, and Chemical Command (AMCCOM), which is a subordinate command to the Army Materiel Command (AMC), is the service manager for CWM. This agency along with the DESCOM who managers Army Depots, controls all installations that have a Chemical Surety Mission. In this capacity, AMCCOM was tasked by AR 50-6 to provide the closest surety location for found munitions. Again because of legal problems to be discussed later, AMCCOM had a get deal of difficulty in complying with this mission. For whatever reason, AMCCOM unofficial policy tended to be; for truly accidental finds of CWM, TEU would transport to a Chemical Surety Facility. If however, a CWM removal action or remediation occurred that was planned to include risk assessment, health and safety plans and work plans, it could not be supported by AMCCOM. The catch

phrase was, "Just don't dig". This philosophy was later changed, not from with in the Army but through Congressional Pressure brought to bare over Fort Segarra and Raritan Arsenal.

4.4 The first in many cases to feel this political pressure was the Huntsville Division of the Corps of Engineers (CEHND). As the fledgling Mandatory Center of Expertise and Design Center for Ordnance and Explosive Waste, of which CWM is a subset by definition, CEHND manages the Inventory Project Report (INPR) system. Under this system Formerly Used Defense Sites (FUDS) are identified by districts and recommended for remediation projects. It soon became obvious that there was a problem, there was no method in place to deal with suspected CWM contaminated sites. During the last two years, CEHND has gone to numerous Army agencies for a solution to this problem. Between political pressure and several other agencies assistance, several of the legal and technical hurdles were overcome.

4.5 The most relevant and important event was the formation of the office of the Project Manager, Non-Stockpile Chemical Materiel Destruction. At this point in time this office answers directly to the Deputy Assistant Secretary of the Army for Installations, Logistics, and Environment. Eventually it will be a sister agency to the Chemical Demilitarization Program. Both will be under the U.S. Army Chemical Materiel Destruction Agency (USACMDA). This agency was formed on 22 Jun 1992, earlier than originally planned. As stated in the Vice Chiefs memorandum, "USACMDA" will provide overall direction to include resource programming, environmental documentation for transport mode and storage site selection, and the development of equipment and procedures. The USACMDA focus for the time being is on Former Raritan Arsenal and Former Ft. segarra as directed by the Vice Chief of Staff. USACMDA has started its mission with an extremely ambitious Scope of Work to its current contractor to look at programmatic issues as well as specific issues dealing with the two sites. Some issues being looked at but not all inclusive are transportation, permitting, destination, on site treatment and on site lab capability.

5.0 PLANNING AND ALTERNATIVES

5.1 Legal changes have been constantly forth coming. Changes and even additions to the Army's view as to how to treat recovered chemical warfare materiels have occurred with ever increasing regularity.

5.1.1. As of this date the Office of Army Counsel has formally stated that because it meets the characteristics of the Resources Conservation and Recovery Act (RCRA) Hazardous and Toxic Waste

definition and therefor will be treated under RCRA. Although this is the official position of the Army Counsel, it is widely disagreed with both in the Army and in the civilian sector.

5.1.2 One of the chief reasons behind this position is typically one of self imposed abuse that stems partially from the trial of the "Aberdeen Three". These Department of Army employees have been used as an example to instill dread throughout the Environmental community. At the out set of the ongoing Raritan and Fort Segarra issues, one could not attend a meeting without this trial being brought up and someone fearfully predicting the doom of jail time. There are two points of view without the benefit of information about the "Aberdeen Three". One holds to the belief that these three innocent government employees, while doing their jobs as set forth in the job descriptions and as directed by proper military authorities, were abandoned to face the State of Maryland Regulators without any financial or other help from their employers. In other words, while doing what they were told, they took the fall or blame for the Army. Recently, it was stated that they had each paid over $80,000 out of their own pockets for their legal defense. Personal liability has been a constant fear ever since the verdict. The second view however, is much different. That opinion states that these three were, unknown to their employers, knowingly and intentionally dumping hazardous chemicals. They further attempted a cover-up and in fact, part of the rumors include misappropriation. The point here is not to rehash what actually happened but to show how the whole issue has become much more than it actually was.

5.1.3 To further complicate the issue of RCRA, previous Commanders at Installations that have a Chemical Surety Mission, cut deals with state regulators so that the states had a definite impact on the operation and the mission of that installation. At no other time in the history of the United States and in no other issue have states been given primacy over military missions and issues. But by capitulating to state regulators by getting Hazardous Waste Storage Permits these former installation commanders have set the precedence that the Army Counsel is following. That is that CWM is HTW and therefor controlled by RCRA. There are three basic problems associated with that position.

5.1.3.1 The first is that many things have the characteristics of HTW and are not specifically addressed by the Army Counsel as HTW. The batteries in a lap top computer have the characteristics of HTW.

5.1.3.2 RCRA, as defined by GAO is used to regulate and control current Hazardous Waste Generators. It is not used for the remediation of sites that have been abandoned. The exception to this is when an installation is characterizing "all" Solid Waste Management Units in conjunction with its application or renewal of its RCRA Part B permit.

5.1.3.3 Finally, RCRA is enforcable by the Environmental Protection Agency and may be delegated to state agencies. However, the removal response authority for Ordnance and Explosive Waste (OEW), of which CWM is a subgroup, lies with the Department of Defense. In turn, this has been further delegated though the Department of the Army and the Chief of Engineers to the Commander of the Huntsville Division of the Corps of Engineers. As the removal authority, and operating under the National Contingency Plan, the Corps of Engineers has operated effectively in environmental remediation of OEW operating under the Comprehensive Environmental Response, Compensation, and Liability Act or CERCLA. Although all RCRA requirements are met, no permits, State, Local, or Federal are required. This becomes the major issue currently affecting the CWM clean-up program. The differences of who is the regulatory authority is only one reason that this issue is a major problem. In the next few paragraphs, some of the stumbling blocks will be reviewed.

5.1.4 While digging a trench for a pipeline at Redstone Arsenal, Al., a contractor unearthed approximately eighteen 4.2 inch mortar rounds and one two pound incendiary bomblet. These were investigated by a team from the Explosive Ordnance Disposal (EOD) Division of the Ordnance Missile and Munitions Center and School (a tenant organization at Redstone Arsenal). The EOD team was able to determine that the rounds were unfuzed and that some contained a liquid filler. As Redstone Arsenal is the site of one of the largest CWM manufacturing, storage and test facilities during World War II, the rounds were immediately suspect of containing CWM. The rounds were placed in double plastic bags. Vapor samples were collected from inside the bags after a wait time for vapors to collect, and the 4.2 inch mortar rounds were evacuated to storage bunker belonging to the EOD Division. The installation environmental office was notified and the two pound incendiary bomblet destroyed at the EOD training range. By the time this entire incident was finished (two years later) because the environmental office listed all recovered items as HTW no Surety Installation would accept them (Surety Installation RCRA permits did not cover HTW). The EOD Division was chastised for unauthorized disposal of Hazardous Waste (their range was a training range). Redstone violated RCRA by storing hazardous waste without a permit. Once an exception was granted and the rounds were taken to Anniston Depot, they had to be stored by

themselves because the compatibility could not be determined, i.e. they could not be sampled without opening their contents to the atmosphere, which is prohibited. Thus we, the Army, however well intentioned have created an administrative gridlock. We have called CWM HTW, then we have tried to apply the standard such as the use of deadly force and security criteria to these rounds as directed by AR 50-6 and AR 190-59. The bottom line here is, because we have painted ourselves into a corner, we can not remediate CWM found either on Formerly Used Defense Sites or on active installation without violating a law or a regulation.

5.1.5 USACMDA's first real roles will be to unlock this gridlock. Whether CERCLA and the NCP or RCRA or both apply, USACMDA is attempting to determine what can be accomplished. The technical skills and abilities are available to find, recover, package, and transport or neutralize on site CWM. But, until the legal issues are resolved, the regulatory authority established, and a place licensed to receive this materiel, remediation cannot begin. The question remains what do you do with a CWM round if you find it, and not violate laws and regulations.

5.1.6 Further, while this legal issue is on the table, the outcome has little to do with the terms of the chemical weapons treaty now in negotiations. In fact it is thought that recovered rounds containing CWM will be counted in the treaty because they may be fully functional weapons. This in itself may significantly affect the legal views, some of which have refused to acknowledge the fact that these are lethal weapons intended to kill. It matters very little that the intent of the person burying a round was to dispose of it, which has been stated as a test for RCRA and HTW. It may still be a fully functional weapon.

5.2 The storage and transport issue aside, other facilities are needed for a successful remediation. The next few paragraphs discuss the current thoughts on remediation techniques that will be employed.

5.2.1 Before intrusive excavation is to begin and after the site is prepared for intrusive work by surveying, geo technical mapping, soil and water sampling, the question of unexpectedly finding an intact weapon must be address. Even if samples show no trace of CWM or break down by products, the possibility of finding an intact round is always present. These suspect sites were not chosen at random. Extensive archive searches and all available information has been gathered in an attempt to insure that some past event points to CWM and that every effort is made to identify and locate these items with records. As already seen, transporting to an existing facility may not be possible.

The proposed solution is to used milvan type containers designed to store hospital waste. These refrigerated containers could be secured and guarded on or near the remediation site. After recovery, surface decontamination and preliminary packaging, the rounds would be placed in these vans. Not only are they ideal for control. They afford an environment that enhances storage. If the munition contains mustard (HD) the refrigerator would successfully freeze it (HD freezes to solid form around 58 degrees F.). For other agents, the cooling would deter expansion of the agent due to heat and be less likely to leak. The round in the refrigerated milvan would then be guarded, not only to the extent required by regulation, but to insure public trust and confidence.

5.2.2 During the actual intrusive work, a prefabricated, portable building will be erected over the remediation site. This type building is big enough to allow use of a backhoe and several workers and would contain vapors that may be released during excavation. Air monitoring and filtration would warn of elevated levels of air contamination and insure no release to the out side. Air monitoring would be done outside the building as a precaution. This facility is intended to contain any vapors and to instill confidence in area residents who have an unrealistic idea of the effects of CWM.

5.3 Although the Army has worked with CWM for years, all operations have been on fixed installations. All FUDS operation don't have that luxury. Therefore, certain items of equipment must be developed. For instance, at present, when samples are taken (soil and water) they are escorted to a surety laboratory by TEU personnel. When analysis has been completed, weeks may have lapsed. When contractors mobilize and are on site, these kinds of delays account for very large amounts of wasted money. On site labs must be available for fast turn around of analytical data. Another area of equipment need is for real time air monitoring. The Army has real-time air monitoring equipment with the ACAMS and MiniCAMS. Two disadvantages are seen here. These systems require spike samples to use for real time comparison. Sample spikes must be escorted to the site by TEU personnel. Also, this equipment is capable of single agent monitoring so several sets must be on each site at all times unless the agent is positively known. Finally, there is no real time monitor capable of monitoring for Lewisite which is arsenical based. There are other equipment issues that have to be addressed as well.

5.3.1 Another issue is whether OSHA standards are acceptable to the Army for working with these CWM agents. This is important for the contractor who is working on site in OSHA approved Level

A Personal Protective Equipment and is not in compliance with Army Standards. It would seem necessary for the Army and OSHA to have identical standards when dealing with CWM. In addition, if the Army standard is the M3 butyl rubber suit, with temperatures ranging from 80 to 100 degrees F. year round at Former Fort Segarra, the stay time would be almost work prohibitive. In order to effectively remediate a site, workers should be able to labor for two to four hours. In that heat, this could only be accomplished with cooling suits which have not been very effective with the M3 suit.

6.0 FORESEEABLE FUTURE EVENTS

6.1 The immediate foreseeable future at Former Raritan Arsenal starts with a surface sweep to begin on or about 1 Sep 1992. This will be done by contractor and will be enhanced by the use of magnetometers to insure that the search crews are able to avoid stepping on any surface OEW. The area has been previously search and some geo physical work done. There has been no evidence of OEW on the surface in the past. However, there is debris, of which some is believed to be connected to CWM activities. This is in the form of containers not likely to be contaminated by agent. These containers will however be treated as 3X, meaning surface decontaminated. All debris will be segregated into two types, 3X and non 3X. These will at a later date either be taken to a Surety Facility or an HTW facility depending on the results of soil and water sampling and swipe samples.

6.1.1 During the surface sweep phase, surveying will take place to identify the exact original boundary of the area. In addition, foliage and surface soil samples will be taken and sent to a Surety Laboratory for analysis. Determination has not yet been made as to whether bore samples need to be taken of the larger trees in the area.

6.1.2 This is the first portion of site characterization. The surface clearance is to be done with the intent to make the area safe for brush clearance. The next phase planned for November 1992 is to clear all vegetation six inches or less in diameter, off the site to facilitate geo-physical work. This work will consist of magnetometer, metal detector, and ground penetrating radar mapping to determine the exact location, dimension and depth of burial trenches. Further soil sampling to a depth of up to ten feet will be done along with shallow ground water monitoring wells. Another test will be to probe near the buried anomalies and collect and analyze gas samples. Finally, the vapor barrier will be constructed and a test trench dug to determine exactly what is in the ground by retrieving a sample.

6.1.3 In conjunction with the above, with investigation results constantly feeding into it, a Remedial Investigation and Feasibility Study (RIFS) there will be conducted. As the results become more clear, decisions will be made that will point to the recommend course of action to take. This may be any number of possibilities or combination there of. For instance, if no contamination is found and buried anomalies are not OEW/CWM, then the decision may be to do nothing. If samples show that other types of contamination are present that are not related to OEW/CWM, then the area will be remediated for HTW. The decision may be to treat on site or to transport to a Surety Facility. Whatever the recommendation, the results will all be forwarded to the level of the Secretary of the Army for a final determination and a Record Of Decision (ROD).

6.2 At the same time that the RI/FS is going on USACMDA will be conducting Environmental and Feasibility studies for a programmatic approach to the final disposition of recovered CWM. This will include many options such as transportation or on site neutralization. Some of the data from Raritan will be used in this study.

6.3 Former Fort Segarra follows closely behind Raritan in the time table. However, there are separate issues that have to be addressed at Fort Segarra. Part of these issues include ownership and responsibility for hurricane debris removal. Assuming these issues can be overcome fairly quickly, Fort Segarra follows each step completed at Raritan by three to six months.

7.0 CONCLUSIONS

7.1 The most important element in this entire effort is the continued close coordination between USACMDA and the Corps of Engineers. As long as both agencies are aggressively pursuing the same goal of successful remediation of sites contaminated with CWM, the process will run smoothly. There is currently an estimate of over 200 sites in the United States and its territories that may be contaminated with CWM. They range in size and complexity from a several thousand acre arsenal to a eight feet in diameter and six feet deep hole in the ground on the Kansas plains. It is obvious that this is a multi-year/multi-billion dollar program.

GUARD AND SECURITY DIVISION
CHEMICAL WARFARE CENTER
Edgewood Arsenal, Maryland

JFG/wcd
30 September 1944

SUBJECT: Report of a Guard and Security Detail.

TO : Personnel Division, OC-CWS, Gravelly Point, Virginia, (through Post Adjutant, Edgewood Arsenal, Maryland.)

EXTRACT

* * * * *

3. 0130 19 September 1944. Group #1, with three-hundred (300) pounds of excess baggage consisting of decontamination material, departed Washington National Airport and proceeded by air via Eastern Airlines to St. Louis, Missouri and Transcontinental & Western Airlines from St. Louis, Missouri to Kansas City, Missouri, arriving at 0830 19 September 1944. Group #2 of detail departed Washington National Airport and proceeded by Airlines enroute to Kansas City, Missouri, arriving at 1630 19 September 1944. Upon arrival at destination each group was met by government transportation, from Ft. Leavenworth, Kansas, which took the personnel to Marysville, Kansas. Group #1 stopped at Ft. Leavenworth, on way to Marysville, Kansas, and officer in charge of detail reported to Major Ketzler, Post Adjutant. Group #1 and Group #2 arrived at Marysville, Kansas at 1400 and 2200, respectively, on 19 September 1944.

4. Upon arrival at Marysville, Kansas, officer in charge reported to Union Pacific officials at the station at Marysville, Kansas and also Major Earl Carter, Chemical Officer, 7th Service Command, who was also present. Detail immediately proceeded to the two (2) cars containing the leaking drums, which were located on a "Y" about two (2) miles north of Marysville, Kansas, outside of the freight yards. In all there were three (3) leaking drums (55 gallon) of Mustard (H).

5. As soon as personnel of the detail was dressed in impermeable protective clothing, the cars were opened and entered for inspection, to determine the seriousness of the leakage. Liquid Mustard (H) had dripped through the flooring of the two (2) cars and was found on the bolsters, cross beams, and trucks of both cars. Missouri-Pacific car #47926, a wooden car, was in a more serious condition, but contained only one (1) of the three (3) leaking drums. The two (2) drums, in Union-Pacific car #188940, a steel car, were of a less serious nature. Agent in all three (3) drums had to be destroyed since there was no means available of transferring the Mustard (H) from the leaking drums to other drums. Since more decontamination material was required, Pine Bluff Arsenal, Arkansas was contacted to make the necessary shipment, which

consisted of approximately eight hundred (800) pounds of protective clothing and equipment. Authority for shipment of decontamination material from Pine Bluff Arsenal, Arkansas to Marysville, Kansas was given by Colonel Gillet, Supply Division, OC-CWS, Washington, D. C., who had been notified of the seriousness of the leakage. Shipment of material, from Pine Bluff Arsenal, Arkansas, was made by Railway Express on 19 September 1944. Pending arrival of the decontamination material from Pine Bluff Arsenal, Arkansas, the contents of the two (2) contaminated cars, with the exception of the three (3) leaking drums, were transferred to Southern Railroad car #261588 and Seaboard Ariline car #19135, respectively, from Missouri-Pacific and Union-Pacific cars, and braced and packed for shipment to Pine Bluff Arsenal, Arkansas. All drums were checked for possible leakage and contamination during the reloading operation. After the loading had been completed, the leakers were observed more closely and found to be leaking as follows:

a. Drum #179754, in Missouri-Pacific car #47926, had a six (6) to seven (7) inch crack, slighly off center, in the face of the bottom of the drum. liquid Mustard (H) continuously dripped through this crack. Crack is believed to be due to rust and corrosion, the result of out-door storage and lack of paint. All drums in both cars were rusty and had not been painted for quite some time.

b. One (1) drum, #162061 in Union-Pacific car #188940, had a hole or puncture about one-half (1/2) inch long and about two (2) inches below the rim of the head of the drum. Each jolt of the car resulted in the splash of the liquid Mustard (H) through the hole onto the walls and floor of the car. Hole appeared to be the result of careless use of tools such as a wrecking-bar, claw-hammer, or crow-bar.

c. The other drum, #82242 in Union-Pacific car #188940, had a fracture in the welded rim on the bottom of the drum. Such is not uncommon but in this particular instance, weld looked as if it had been faulty for some time. Leak seemed to be the result of too much buffing or filing, immediately after welding. If such be the case, drum could have been leaking slightly at the time of loading at Deseret Chemical Warfare Depot, Tooele, Utah. During the time the detail was reloading the two (2) cars, a section crew from the railroad was digging a hole approximately three (3) miles north of Marysville, Kansas in which the contents of the three (3) leaking drums could be destroyed. Dimensions of the hole were: four (4) feet wide, eight (8) feet lone, and six and one half (6 1/2) feet deep. Hole was in accordance with regulations and was dug near Mile Post 116, on railroad property, away from drainage ditches, highways and points of likely excavation.

6. Detail was ready to destroy and bury the Mustard (H) on 21 September 1944, but decontamination material had not arrived from Pine Bluff Arsenal, Arkansas. A second "gas-train" of forty-five (45) cars of Mustard (h) passed through Marysville, Kansas at 1300 21 September 1944 enroute to Pine Bluff Arsenal, Arkansas, escorted by a Guard and Security Detail under the command of Lt Hoffman, Guard and Security Division. Lt. Hoffman had with him, one-thousand, five-hundred (1,500) pounds of Grade BB Calcium Bleach and fifteen (15) gallons of DANC. This detail, borrowed from Lt.

Hoffman, fifteen (15) gallons of DANC and four-hundred (400) pounds of Calcium Bleach. With this decontamination material the contents of the three (3) leaking drums were destroyed 21 September 1944. It was necessary to use four hundred and fifty (450) pounds of calcium Bleach, two-hundred (200) gallons of water, and ten (10) gallons of DANC in destroying the contents of the three (3) leaking drums. Clearance on the tracks was obtained for one and one-half (1 1/2) hours, while the dumping and destroying operation was being carried out, and no rail traffic was permitted to pass. The three (3) leaking drums, with five-hundred (500) pounds of Calcium Bleach, ten (10) gallons of DANC, necessary tools and other equipment was being carried out, and no rail traffic was permitted to pass. The trhee (3) leaking drums, with five-hundred (500) pounds of Calcium Bleach, ten (10) gallons of DANC, necessary tools and other equipment was carried up the tracks on a section car, which had a false floor of one (1) by twelve (12) covered with tar-paper, built especially for this purpose. All equipment and the car were set off the track at the hole. Slurry was mixed and the Hoods and Masks were adjusted on all personnel and the destroying operation began. At this time all railroad personnel were six-hundred to eight-hundred (800) yards up wind and only the personnel of the detail were present at the hole where the Mustard (H) was being destroyed. The Mustard (H) and Slurry were poured into the hole simultaneously until all the drums had been drained. Hole was filled with alternate layers of dirt and bleach. Sign was posted, reading "POISON GAS" with the date plainly printed on it. The outside of the drums were then decontaminated, loaded on the flat car and returned to the loaded freight cars. Here, they were once again decontaminated, the leaks or holes sealed with Litharge and Glycerine. The three (3) empty drums, containing the contaminated Sulphur residue, were loaded, packed, braced, and shipped to Pine Bluff Arsenal, Arkansas, for destruction or salvage. The two (2) newly loaded cars, one of which carried the three (3) empty drums, departed Marysville, Kansas 22 September 1944 for Pine Bluff Arsenal Arkansas, with Col. Prince, a member of a Guard and Security detail under the command of Lt. Gower, Guard and Security Division, as security guard. The wood lining of the inside of the two (2) cars was torn out and burned. The lining in the cars that was destroyed was as follows:

a. In the Union-Pacific car #188940, the entire end lining, the siding for one-half (1/2) the length of the car and six (6) feet high, about fifteen (15) feet of flooring on the contaminated end of the car.

b. In the Missouri-Pacific car #47926 the end of the car, which was metal, was decontaminated with DANC, but siding on both sides about two (2) feet high and one-half (1/2) length of car and about twelve (12) feet of flooring were destroyed.

All contaminated metal parts such as the metal ends and sides of the cars, the steel bolsters and cross-beams, the under-carriage and trucks were all decontaminated by use of kerosene and brushes, DANC, and then were finally steamed for about two and one-half (2 1/2), or three (3) hours, and then washed with water. All ground likely to have been contaminated, all tracks

that the cars were on, and all railroad equipment was washed with DANC or covered with Chloride of Lime. A total of six-hundred (600) pounds of Grade HB Calcium Bleach, twenty-five (25) gallons of DANC, ten (10) gallons of kerosene were used for decontamination in addition to the steam and water. The area were agent was buried was checked for odor, but no odor was detected, this being the last thing detail accomplished before departing Marysville, Kansas. The work of decontamination was started 19 September 1944 and was completed at 1200 23 September 1944. There were no casualties or severe burns among, either, military or civilian personnel. All members of the Guard and Security Detail did receive slight vapor burns, which were no more serious than a case of sun-burn.

7. A **

*   *   *   *   *

/s/ JERRY F CLEASON
/t/ JERRY F CLEASON
2nd Lt., CWS
Guard and Security Division

A CERTIFIED TRUE EXTRACT COPY

U.S. ARMY CHEMICAL CORPS
TECHNICAL ESCORT UNIT (1602)
Army Chemical Center, Maryland

CHLMC-TE-OP (Project Report 140-61)

SUBJECT: Report of Investigation of the Chemical Agent Burial Area at Raritan Arsenal, Metuchen, New Jersey

I. INTRODUCTION

A. MISSION

To investigate the Chemical Agent Burial Area (Area 5 on the Arsenal map) at Raritan Arsenal, Metuchen, New Jersey (Raritan) to determine if residual contamination exists in the soil.

B. REQUEST FOR INVESTIGATION

Technical Escort Unit services were requested by Lt. Col. H.G. Shade, Executive Officer, U.S. Army Chemical Corps Materiel Command, Army Chemical Center, Maryland, on 26 June 1961.

C. COMPOSITION OF INVESTIGATION TEAM

The Investigation Team consisted of:

James L.E. Hill	1st Lt	077860	OIC
Burnis G. Neal	MSgt	RA34428044	Member

II. EXECUTION

A. GENERAL BACKGROUND

Civilian workers at Raritan who had worked in or around subject area during the time of the burial operations revealed the following information upon being questioned by the Investigation Team:

1. During the period 1943-1945 when Raritan was utilized as a shipping port for vessels transporting munitions and equipment overseas, chemical munitions and/or containers which developed leaks were transported to subject area for disposal. Leaking munitions and containers were also transported by barge to Raritan for disposal. The filler for these containers and munitions was, in all cases, mustard (HD). In addition, all containers were of the 55-gal drum type and all munitions were of the 100-lb bomb type.

2. A small detachment of Chemical Corps personnel, assisted by civilians, was assigned the task of disposing of these leakers. The disposal procedure utilized by this detachment consisted of digging a pit 5' by 5' by 5', pouring the liquid mustard out of the munition or container into a decontaminating solution contained in the pit, and then placing the empty containers or bomb casings into the pit. The pit was then covered with earth and signs were posted over it indicating the date of burial, the type of agent buried and a warning against digging in the area. No accurate estimate of the number of pits dug in the area could be obtained.

3. In more recent years, an unknown quantity of potassium cyanide was buried in the area. This compound was buried by the Post Engineers after Raritan ceased utilizing it as a fumigant. The Explosive Ordnance Disposal Squad stationed at Raritan has also, in recent years, utilized a portion of the area in the disposal of red fuming nitric acid by neutralization.

B. INVESTIGATION PROCEDURES

1. The Investigation Team departed Army Chemical Center, Maryland at 270900 June 1961 and arrived Raritan Arsenal, Metuchen, New Jersey at 271320 June 1961. Upon arrival, the Team met with Mr. Louis Jezek, Safety Branch, Office, Chief of Ordnance, Mr. Frank Mish, Ammunition Project Officer, Raritan and Mr. Arnold E. Ohlson, Asst. Safety Director, Raritan. The Investigation Team then accompanied the above-named individuals on a reconaissance of the subject area in addition to other area suspected of being contaminated with explosives and/or munition components.

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Following the reconaissance, arrangements were made with the Post Engineers to procure necessary equipment for investigation of the burial area.

2. The area in question is a triangularly shaped section of level terrain which covers approximately 450,00 square feet. It is overgrown with vegetation ranging in height from two to six feet. Soil within the area is sandy with small pieces of gravel interspersed throughout. Test holes dug at various locations in the area established the water table at five feet. A portion of the area approximately 50 by 70 yards is bordered by blank, metal sign posts driven into the ground.

3. At 0830 hours, 29 June 1961, the Investigation Team began its investigation in the area. Initially, probing and excavation was attempted in portions of the area situated outside of the smaller area bordered by sign posts. These operations failed to uncover any evidence of contamination or old burial pits. At this point, Mr. Alvin Larson, Surveillance Inspector who had worked in the area during the burial operations, appeared on the scene and pointed out specific points within the sign post bordered area where burial pits had been dug. Five areas, each approximately 25 feet square, were selected for excavation after probing had indicated solid objects were present beneath the surface of the ground. Employing a bull-dozer with a back hoe attachment, the five selected areas were excavated to a depth of three feet. At this point, a post hole digger and a shovel were utilized in order that the bull-dozer would not become grossly contaminated in the event the chemical agent was still actively present in the bottom of the pit. Further excavation to a depth of four feet in each of the pits uncovered traces of a white substance which appeared to be bleach or lime. Also, the distinctive odor of mustard could be detected in each excavated pit and downwind approximately ten yards from the area in question.

Digging further to a depth of four and one-half to five feet in each of the pits bombs of the M47 type, were uncovered. None of these bombs contained a fuze or burster. Soil samples were taken at depths of one and four and one-half feet. Since water was struck in each of the pits between four and one-half and five feet, it was decided to cease excavation due to a limitation of equipment and time. It was also felt at this time that sufficient data had been gathered in order that a decision could be made regarding contamination of the soil within the area. Tests were made in the area with the Chemical Agent Detector Kit, detector paper and detector crayon. At the conclusion of the tests, the excavations were covered over and the equipment utilized in the operation was decontaminated and cleaned.

C. FINDINGS

1. The odor of mustard detected by the Investigation Team upon excavating to a depth of four feet gave the first indication that the agent was still actively present in the soil. Tests with the Chemical Agent Detector Kit in the bottom of the excavations resulted in a weak but still positive test for the blister agent group of which mustard is a member. Heating of test tubes containing soil samples from a depth of four and one-half feet yielded, in all cases, a very strong positive test for the blister agent group. Positive tests could not, however, be obtained with detector paper or detector crayon nor could positive tests with the Chemical Agent Detector Kit be obtained from soil samples taken at a depth of one foot.

2. The Investigation Team was not properly equipped to make tests to determine if contamination exists from the burial of potassium cyanide or the neutralization of red fuming nitric acid in the area.

D. DISCUSSION

As a result of the findings listed in paragraph C above, the following conclusions may be drawn:

1. Vestiges of the mustard buried during the period 1943-1945 still exist in the soil in an active condition at a depth of four and one-half feet. Although soil samples taken at one foot did not yield a positive test with the Chemical Agent Detector Kit, this does not constitute a clearance for soil at this depth. A chemical analysis of this soil would have to be made before this fact could be established.

2. The distinct possibility also exists that, as a result of the agent buried at depths at and below the present water table, traces of the agent may have migrated throughout and even beyond the boundaries of the burial area.

3. The problem of contamination resulting from the burial of potassium cyanide cannot be accurately evaluated since no traces of this compound were knowingly uncovered and no information was available on the exact place or depth of burial, type of containers, or total amount buried.

4. The probability of contamination resulting from the disposal of red fuming nitric acid is considered very small. Two reasons exists for this belief. One, discussions with personnel assigned to the Explosive Ordnance Disposal Squad who participated in the acid disposal strongly indicates that adequate procedures were utilized which should have insured the complete neutralization of the acid. Secondly, even if some of the acid had not been neutralized at the time of disposal, repeated dilution with natural water in the soil during the passage of time would have rendered it relatively harmless.

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E. RECOMMENDATIONS

The question now arises - what can be done to protect personnel from the contamination in the area? Two possible solutions exist.

1. Procedures have been developed whereby trained and properly equipped personnel of the Technical Escort Unit can decontaminate areas of this nat[illegible]. However, due to the depth of the burial pits, the [illegible] which would be encountered upon excavation and the [illegible]ive overgrowth of vegetation, the operation would involve considerable expense and the expenditure of much time and effort.

2. The area could be enclosed by a high barbed wire fence and posted in accordance with paragraph 229, TM 3-250. Although this method does not eliminate the existing contamination in the soil, it will - if its warnings are heeded - prevent personnel from being exposed.

s/JAMES L.E. HILL
1st Lt Cml C
Investigating Officer

Enclosure 3

Location Key

ACY	American Cyanamid Chemical Company - Azusa, California
ANAD	Anniston Army Depot - Anniston, Alabama
BAAB	Brooksville Army Air Base - Brooksville, Florida
BARB	Barbers Point Naval Air Station, Hawaii
BHOD	Black Hills Ordnance Depot - Igloo, South Dakota
BRAG	Ft. Bragg - North Carolina
CAAA	Crane Army Ammunition Activity - Indiana
CAAF	Campbell Army Air Field - Kentucky
CHAS	Charleston Naval Weapons Station - South Carolina
CNAD	Crane Naval Ammunition Depot - Crane, Indiana
CON	Naval Weapons Station - Concord, California
CZ	Canal Zone Tropical Test Areas
Deseret	Deseret Chemical Warfare Depot - Utah
DOW	Dow Chemical Company - Pittsburg, California
DPG	Dugway Proving Ground - Utah
EA	Edgewood Arsenal - Maryland
ELM	Elmendorf Air Force Base - Alaska
ENJ	Colts Neck Naval Pier - Earle, New Jersey
FALL	Fallon Naval Air Station - Nevada
FCA	Fort Churchill - Rivers, Manitoba, Canada
FMC	Fort McClellan - Alabama
FTR	Ft. Richardson - Alaska
FTST	Ft. Stewart - Georgia
GAAF	Godman Army Air Field - Ft. Knox. Kentucky
GAK	Ft. Greely - Alaska

Location Key (Continued)

GCWD	Gulf Chemical Warfare Depot - Huntsville, Alabama
GUAM	Anderson Air Force Base - Guam
HAAP	Hawthorne Army Ammunition Plant - Nevada
JA	Johnston Atoll
KEY	Keyport Naval Torpedo Station - Washington
LALM	Los Alamitos Naval Air Station - California
LBDA	Lexington-Blue Grass Depot Activity
LEJ	Camp Lejeune - North Carolina
LLL	Lualualei Naval Magazine - Hawaii
LOD	Letterkenny Ordnance Depot - Pennsylvania
LRAFB	Little Rock Air Force Base - Arkansas
MAAB	MacDill Army Air Base - Tampa, Florida
MAAP	McAlester Army Ammunition Plant - Oklahoma
MAFB	Maquire Air Force Base - New Jersey
MAP	Mukilteo Ammunition Pier - Mukilteo, Washington
MCMA	Mineral County Municipal Airport - Nevada
MMA	McAlester Municipal Airport - Oklahoma
NAAP	Newport Army Ammunition Plant - Newport, Indiana
NAVG	Naval Magazine - Guam
NAZ	Navajo Army Depot - Arizona
NMD	Naval Mine Depot - Yorktown, Virginia
NOPE	New Orleans Port of Entry - Braithwaite, Louisiana
NRAF	New River Marine Corps Air Field - North Carolina
OKC	Chibana Army Depot - Chibana, Okinawa

Location Key (Continued)

PAAF	Phillips Army Air Field - Aberdeen Proving Ground, Maryland
PAFB	Pope Air Force Base - North Carolina
PBA	Pine Bluff Arsenal - Arkansas
PNMA	Pendleton Municipal Airport - Washington
PUDA	Pueblo Depot Activity - Pueblo, Colorado
QUAN	Quantico Marine Corps Air Field - Virginia
RAH	Rahway Arsenal - Rahway, NJ
RMA	Rocky Mountain Arsenal - Colorado
SBSB	Small Boat Wet Storage Basin - Charleston, South Carolina
SBCA	Seal Beach Naval Weapons Station - California
SJOD	San Jacinto Ordnance Depot - Houston, Texas
SUF	Suffield Test Center - Ralston, Alberta, Canada
SUN	Sunny Point Naval Pier - Sunny Point, North Carolina
SVOD	Savanna Ordnance Depot - Savanna, Illinois
TAFB	Travis Air Force Base - California
TEAD	Tooele Army Depot - Tooele, Utah
TNM	Theodore Naval Magazine - Mobile, Alabama
TORO	El Toro Marine Corps Air Station - California
TUL	Tulalip Backup Storage Depot - Tulalip, Washington
UKMR	Upper Kipapa Military Reservation - Hawaii
UMDA	Umatilla Depot Activity - Hermiston, Oregon
WAAF	Wainwright Army Air Field - Ft. Wainwright, Alaska
WHID	Whidbey Island Naval Air Station - Washington
WRAF	Wright Army Air Field - Georgia
YTS	Yuma Test Station - Yuma, Arizona

Incident Summarization Sheets

1. (Date: Jul/Aug 47, Ref: 1947, page 1) One 4.2 inch phosgene (CG) filled mortar cartridge was discovered leaking while unloading on the dock. The item was destroyed by immersing it in a decontaminating chemical solution until all the phosgene had been chemically reacted. Then the item was removed for explosive demolition. There were no injuries.

2. (Date: Mar 48, Ref: 1948, page 1) Minor valve leaks were discovered during the movement on two bulk containers of mustard (H). The leaks were sealed and decontaminated. There were no injuries.

3. (Date: Feb 48, Ref: 1948, page 1) A switching accident at Pine Bluff Arsenal resulted in two railcars filled with HT ton containers derailing and overturning. No leakers occurred and there were no injuries.

4. (Date: Jul 47/Jan 48, Ref: 1947, page 1) One minor road accident. No injuries and no leakers.

5. (Date: Aug/Sep 49, Ref: 1949, page 3) Truck 3 of the convoy was involved in a slow-speed collision with a civilian automobile near Jefferson City, Missouri. No leaks, spills or injuries were involved.

6. (Date: Nov 49, Ref: 1949, page 4) Truck 9 of the convoy was involved in a serious (20 mph) accident, with a civilian truck when the police escort in St. Josephs City, Missouri failed to block off an intersection. There were no spills or leaks. Personnel on the truck were injured by the collision (injured neck and back, bruised knee, bruised side, etc.).

7. (Date: Oct 49, Ref: 1949, page 4) During unloading of the trucks, the fact that one 75mm projectile had rolled out of its pallet went unnoticed. The projectile was found later in the day still in the truck at the Ringsby Transportation Company Garage, Denver, Colorado. The projectile was reported to the Army and removed to Rocky Mountain Arsenal without further incident.

8. (Date: Oct 49, Ref: 1949, page 3) The air brakes on truck 8 of the convoy failed causing it to rear-end truck 7 near Bennett, Colorado. A vehicle fire started as the collision was serious, but was quickly extinguished by the escort personnel. There was no leak or spill, but there were some collision oriented injuries.

9 (A). (Date: Nov/Dec 48, Ref: 1948, page 2) During placement of the ton containers in the hold of the vessel prior to sea dump, a valve was accidentally sheared off. A vapor leak occurred but was sealed and decontaminated. There were no injuries.

9 (B). (Date: Nov/Dec 48, Ref: 1948, page 2) During the sea dump, the scuttling crew reported donning masks due to vapor in the hold of the vessel. It is probable that a ton container leaked during movement to the dump site. There were no injuries.

10. (Date: Jun 50, Ref: 1950, page 2) Truck 303 of the convoy was involved in a collision in Red Bird, Wyoming on 8 June 1950. No further details regarding this accident exist in the historical files.

11. (Date: Jun/Jul 50, Ref: 1950, page 2) Upon starting from a dead stop, a tractor and trailer uncoupled causing the trailer to fall forward onto the ground. There was no damage to the load. There were no spills, leaks or injuries.

12. (Date: Sep 46, Ref: 1946, page 10) Three leaking lewisite bombs were discovered during movement from the train to the barge. These were sealed and decontaminated, and then overpacked. There were no injuries.

13. (Date: Aug 46, Ref: 1946, page 9) Mustard bombs were discovered leaking during the unloading of the barge. The leaking bombs were sea dumped with the other bombs and the spill was chemically decontaminated by a team dressed in protective clothing. One Non-Commissioned Officer was injured. Hospitalization was not required.

14. (Date: Aug 46, Ref: 1946, page 9) Leaking chemical munitions were found during the unloading of the S.S. Richardson. They were segregated onto special barges after being sealed and decontaminated. The leakers included 2 German GA bombs, 2 British H land mines, 46 CG bombs and 154 German H bombs. During the handling of these items "three civilian employees of this station received mustard gas injuries in handling contaminated lines to barges containing leaking munitions. None were hospitalized. Eight enlisted personnel received injuries from mustard gas in miscellaneous operations handling leakers. None were hospitalized." The barges were being used to remove unserviceable munitions found on the S.S. Richardson to a sea dumping area.

15. (Date: May/Jun 46, Ref: 1946, page 5) "Hold Number 2 had a considerable concentration of CG from leaking bombs." The hold was ventilated using large fans. The leakers were sealed. The cargo was unloaded by 18 June 1946. There were no injuries.

16. (Date: May/Jun 46, Ref: 1946, page 5) When unloading of the vessel began, personnel were not in protective clothing and leakers were soon encountered resulting in injuries. Both civilian stevedores and military personnel were then put into full rubber protective clothing. Eventually a total of 2 leaking GA bombs and 154 leaking mustard munitions were discovered. The leakers were sealed, decontaminated and overpacked. They were then segregated on the dock for sea dump. "Fifty-two civilians of the Charleston Stevedoring Company were treated for gas injuries, and 10 of them were hospitalized. Nine civilian employees of the Basin were treated for gas injuries and 3 were hospitalized. Eight Army personnel were injured, and 3 of them were hospitalized." All injuries were mustard burns.

17. (Date: Jul 46, Ref: 1946, page 9) Leaking mustard bombs from the cargo hold of the S.S. Francis Lee were taken by barge to Horn Island, Mississippi, and were open air burned. "All working personnel received vapor burns in the wrist area...some men also had slight burns on the neck." These injuries were incurred by the military group which off-loaded and burned the bombs.

18. (Date: Jul 46, Ref: 1946, page 8) The famous "Leaking Nazi War Gas Train." Soon after leaving Theodore Naval Magazine (12 July 1946) leaking German H bombs were discovered in one railcar. This car was detached from the train at Panola, Alabama, the leaks sealed and the car was returned to TNM for inspection and later shipment.

At Amory, Mississippi, a second car was discovered to be leaking seriously (13 July 1946). It was detached and moved to a siding in Bigbee, Mississippi and was left under guard. In spite of this, several railroad employees of the Amory yard ventured too close to the car and received vapor burns. A military escort team from Edgewood Arsenal arrived and by 17 July 1946, had isolated the leaker, decontaminated the area and destroyed the munition. The railcar then was forwarded to Pine Bluff Arsenal without further incident on 21 July 1946.

Meanwhile, the train with the remaining 8 cars had continued on toward Pine Bluff Arsenal. Arriving at the yard in Memphis, Tennessee (late on 13 July 1946), it was discovered that 3 more cars had leakers on board, and that one was very serious. The train had, in fact, contaminated 10 miles of track leading to the yard. Another special escort team from Edgewood Arsenal was sent to Memphis. The tracks were decontaminated, the leaking railcars were separated and decontaminated, and the leaking munitions were isolated and destroyed. These 3 railcars eventually reached Pine Bluff Arsenal on 30 July 1946.

During the Amory and Memphis operations, at least 21 civilian railyard workers received vapor burns from mustard and 2 were hospitalized. At least twenty-five military personnel received both vapor and liquid burns and at least 4 were hospitalized. The final medical report on these incidents lists 60 total gas exposures - 28 at Amory and 32 at Memphis. The injuries were mainly due to the high summer temperatures, poor availability of proper protective clothing and a lack of understanding and cooperation by local military authorities. This incident resulted in the virtual rewriting of chemical movement procedures used at that time.

19A. (Date: May-Jul 46, Ref: 1946, page 5) This ship, the S.S. Francis Lee, like others carrying captured German stocks, was found to contain leakers; however, this ship contained far more leakers than any of the others. These were segregated on the pier after decontamination and were placed on a barge for disposal (see Incident 17). During the unloading of the vessel 375 people were injured by exposure to mustard, and at least 22 people were hospitalized, making this the worst chemical incident the Army has ever incurred during transportation (excluding combat action during World War II). All of the injured were military personnel, or civilian contract personnel to the Army, principally stevedores.

19B. (Date: Jul-Aug 46, Ref: 1946, page 9) Upon opening the last hold of the Francis Lee, the situation was determined to be beyond handling with the resources at TNM. Consequently, the hold was sealed and the ship was moved to Edgewood, Maryland. Here, technical teams off-loaded the last 300 bombs, destroyed them and completely decontaminated the ship. There were 52 cases of minor vapor burns during this operation, and some personnel were briefly hospitalized. The ship was subsequently moved to Baltimore for "moth balling" prior to being placed in long-term storage. During the moth-balling process, three civilians were injured and hospitalized due to contamination which had

gone undiscovered in a remote portion of the bilge. This area was decontaminated by teams from Edgewood. The ship was checked periodically at its naval reserve mooring for the next 3 years, and no further contamination was found.

20. <u>(Date: May/Jun 46, Ref: 1946, page 4)</u> This ship, the S.S. Isaac Wise, contained some leakers. These were destroyed at San Jacinto Ordnance Depot. Five men received mustard vapor burns during the unloading operation - one ship's crewman, three stevedores, and one military escort person.

21. <u>(Date: Jun/Jul 46, Ref: 1946, page 8)</u> A serious mustard leaker was discovered as the train approached Chattanooga, Tennessee. The car was isolated at Tinner, Tennessee. The leaking bomb was sealed and decontaminated, and mustard which had spilled onto the siding was also decontaminated.

22. <u>(Date: Jun/Jul 46, Ref: 1946, page 8)</u> A leaking railcar was discovered upon entering the Georgia Railroad Yard at the corner of Delta and DeKalb Streets, Atlanta, Georgia. The car was isolated and a military escort team from Edgewood Arsenal was sent to decontaminate the area. The siding was decontaminated and the bomb was isolated and destroyed. Some military personnel on the escort team received minor vapor burns, and one air force enlisted man was briefly hospitalized with vapor burns. During this incident civilians in the vicinity of the leak repeatedly refused to be evacuated. Fortunately, the leak was rapidly contained and no civilians were injured.

23. <u>(Date: Jun 46, Ref: 1946, page 7)</u> One railcar was found to contain leaking drums of mustard upon arrival at Gulf Chemical Warfare Depot. The leaking drums were immediately transferred into sound one-ton containers and the drums were decontaminated. There were no injuries.

24. <u>(Date: Apr 46, Ref: 1946, page 3)</u> On 8 April 1946, while at sea, a ton container of chlorine began leaking through a faulty fusible plug. After unsuccessful efforts to plug the leak, the ton container was thrown overboard. There were no injuries.

25. <u>(Date: Mar 46, Ref: 1946, page 2)</u> On 6 March 1946, while at sea, a 150 pound cylinder of chlorine was found to be leaking. After unsuccessful efforts to plug the leak it was thrown overboard. There were no injuries.

26. <u>(Date: Apr/May 46, Ref: 1946, page 4)</u> Eight 1,000 pound phosgene (CG) bombs and six 500 pound phosgene (CG) bombs were discovered leaking during unloading of the S.S. Park [illegible] Twelve were repaired and two were destroyed (see Incident 39). There were no injuries.

27. <u>(Date: Mar 46, Ref: 1946, page 2)</u> Two mustard bombs were found to be leaking upon arrival. These were placed on a barge and dumped at sea. There were no injuries.

28. <u>(Date: Feb 46, Ref: 1946, page 2)</u> A gasoline line broke causing the truck to catch fire near Little Rock, Arkansas. The crew quickly extinguished the fire. There were no spills, leaks or injuries.

29. (Date: Jun 46, Ref: 1946, page 7) A railcar was discovered leaking mustard near Manchester, Georgia. Military escort teams were sent from Edgewood Arsenal, Maryland, to decontaminate the spill and arrived on 25 June 1946. The teams located a leaking bomb on 26 June 1946 and decontaminated it. The railcar was then forwarded to Gulf Chemical Warfare Depot (GCWD) without further incident. During the decontamination operations at Manchester, approximately 6 civilian employees of GCWD received mustard vapor burns. Approximately 14 members of the military escort teams also received vapor burns, and 7 men were hospitalized for approximately 2 weeks.

30. (Date: May 68, Ref: 1968, page 2) During the movement of this train from ANAD to Earle, New Jersey, the train was required to be repositioned while in the Potomac River Railroad Yard, Alexandria, Virginia. During this time two carloads of rockets were uncoupled from the train, and upon departure, were inadvertently left in the yard. When this was discovered, a military team was sent to secure them, and they were subsequently moved to the sea dump area without incident. The rockets in the carloads were completely encased in concrete for the sea dump, and at no time leaked or caused injuries.

31. (Date: Mar 58, Ref: 1958, page 1) Leakers developed during the move as follows: 7 discovered in Elko, Nevada, 23 discovered in Portola, California, 34 discovered in Sacramento, California, and 59 discovered upon arrival in Concord. This resulted in 7 of the 15 gondola cars being contaminated. Load was decontaminated enroute and on arrival. No injuries.

32. (Date: Mar/Apr 58, Ref: 1958, page 1) Leakers developed during the move as follows: several minor leaks discovered in Portola, California, major leaks were apparent by the time the train arrived in Sacramento, California. During off-loading in Concord, about 150 leakers were found in 22 of 20 gondolas. Prompt decontamination and temperatures dipping into the 30's at night prevented a major spill. Spills were confined to the gondolas and were decontaminated. There were no injuries.

33. (Date: Apr 58, Ref: 1958, page 1) Leakers developed during the move. During off-loading, leakers were found in 29 of 30 cars. Prompt decontamination prevented a major spill and spills were confined to the gondolas. Leakers were segregated and rapidly overpacked in propellant charge cans during the off-loading at Concord, and all rail cars were decontaminated. There were no injuries.

34. (Date: Sep 65, Ref: 1965, page 4) The VX spray tank being returned was almost, but not quite, empty. During the movement, the spray tank nozzle leaked a small amount of VX. The military escort team used a powdered and spray decontaminant to clean the spill, and the chemical reaction caused a small on-board fire on the aircraft. The fire was quickly extinguished and there were no injuries.

35. (Date: May 65, Ref: 1965, page 3) During Operation YBF as the USNS McGraw was moving out of San Francisco harbor, another ship turned across its bow resulting in a near collision. The ships cleared each other by approximately 600 feet.

36. (Date: Oct 68, Ref: 1968, page 5) Upon preparing to unload one railcar at Umatilla, the rabbits were found dead. Further inspection disclosed a small leak in an MC-1 bomb (GB) at the edge of the center suspension lug. The bomb was immediately taped to stop the leak and was then overpacked. The area was then decontaminated. There were no injuries.

37. (Date: Sep 68, Ref: 1968, page 4) During unloading of one railcar at Umatilla, a leaking MC-1 bomb (GB) was detected. The leaker was taped and overpacked. The area was then decontaminated. There were no injuries.

38. (Date: Aug 64, Ref: 1964, page 2) During the movement to sea, a ton container of mustard leaked at the valve assembly. The lip of the ton container had filled with mustard and the ton container below was contaminated as well. The team evacuated the barge, suited up in protective clothing and returned to the barge. They then dumped both ton containers over the side and decontaminated the spill on the barge deck. There were no injuries and the rest of the material was sea dumped without further incident.

39. (Date: May 46, Ref: 1946, page 6) Three leaking German phosgene bombs were disposed of by taking them offshore and dumping them in deep water. There were no injuries.

40. (Date: Jul 46, Ref: 1946, page 9) During unloading of the Francis Lee, 33 leaking German bombs were set aside on a barge for sea disposal. These were dumped on 13 Jul 46 20 miles off the coast. While dumping the bombs, a forklift pierced one bomb accidentally, contaminating the barge and allowing the mustard to partially drain. Since the personnel conducting the dump were in protective clothing, there were no serious injuries and the barge was decontaminated. However, the partially drained bomb floated away rather than sinking. It subsequently washed ashore (20 Jul 46) where local residents retrieved it as a war souvenir. The Army recovered the item on 23 Jul 46. Fortunately, the mustard had been flushed from the bomb, broken up by wave action, and had reacted with the seawater. The bomb was completely clean of mustard. There were no injuries to the civilians who retrieved the bomb.

41. (Date: Aug 71, Ref: 1970-1977, page 1) During the loading of the USNS Sealift, one pallet of 15 M55 rockets was accidently dropped approximately 40 feet into the hold of the vessel from a crane. Although subsequent examination showed that some of the rockets had been severely damaged, no spill occurred, and there was no harm to operators or the general public.

42. (Date: Aug 77, Ref: 1970-1977, page 2) Prior to Army inspection, and prior to arrival in the North Area of Tooele Army Depot, one of two engines scheduled to pull the munitions train was involved in a collision when its brakes failed allowing it to roll into another train. Although no weapons were involved in this crash whatsoever, the event was widely covered by the media, so it is mentioned here for clarification. No chemicals were involved in or spilled during this accident. The engine was replaced, and the actual movement operation proceeded without incident.

Enclosure 4

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF STAFF
WASHINGTON, D.C. 20310

1 JUN 1992

MEMORANDUM FOR ASSISTANT SECRETARY OF THE ARMY FOR INSTALLATIONS, LOGISTICS, AND ENVIRONMENT
COMMANDER, U.S. ARMY MATERIEL COMMAND
CHIEF OF ENGINEERS

SUBJECT: Restoration of Formerly Used Defense Sites (FUDS) Contaminated with Suspect Chemical Weapons (CW) Materiel

1. High level public and governmental attention to the restoration of Raritan Arsenal, NJ and Fort Segarra, VI make it mandatory that we accelerate actions for the recovery of suspect chemical warfare materiel from them. The U.S. Army Chemical Material Destruction Agency (USACMDA) is being formed to accomplish overall programmatic planning and prioritization of effort to clear the estimated 200 formerly used defense sites (FUDS) which also may have suspect CW materiel contamination. USACMDA is designated as the lead agency for recovery of CW materiel from Raritan Arsenal and Fort Segarra. Corps of Engineers and AMC will provide support in the execution of operations to clear these specific sites.

2. Due to the urgency, Raritan Arsenal and Fort Segarra will be pilot projects and planning will proceed as rapidly as possible. Raritan Arsenal will have first priority. On-site activity at Raritan Arsenal will begin as soon as it can be arranged. AMC will provide five borrowed civilian/military personnel as augmentation for USACMDA to facilitate start of planning, pending the hire of permanent personnel. Target job description and grade structure are shown at Enclosure. Specific skills and grade will be worked out between USACMDA and AMC.

3. The restoration of Raritan Arsenal and Fort Segarra will be carried out under ASA(IL&E) policy guidance. USACE retains on-site management responsibility. Director Space and Special Weapons,

SUBJECT: Restoration of Formerly Used Defense Sites (FUDS) Contaminated with Suspect Chemical Weapons (CW) Materiel

ODCSOPS will be focal point for integration of chemical surety, safety, and security policy as it applies to this unique operation.

4. USACMDA will provide overall direction to include resource programming, environmental documentation for transport mode and storage site selection, and the development of equipment and procedures. USACE and AMC support responsibility for Raritan Arsenal and Fort Segarra are assigned as outlined below. Working relationships with USACMDA on a broader scale to address the total restoration mission will be established when the agency becomes fully operational.

a. Corps of Engineers: Responsible for all aspects of site restoration operations to include site investigation, site safety documentation, environmental documentation, remediation actions and unearthing of suspect chemical warfare materiels. Responsibility for CW materiel ends when materiel is unearthed.

b. Army Materiel Command: Responsible in accordance with USACMDA planning for execution of recovery of suspect chemical warfare materiel once unearthed.

5. Funding requirements directly attributable to planning, preparation, and execution of restoration and recovery operations will be resourced from Defense Environmental Restoration Program (DERP) funding. Technical Escort Unit support to USACMDA will be on a reimbursable basis. Storage costs will be executed from AMC normal operating accounts.

Enclosure

DENNIS J. REIMER
General, United States Army
Vice Chief of Staff

Hot Gas Decontamination of Explosives-Contaminated Equipment

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ABSTRACT

Explosives manufacturing, handling, and demilitarization operations at U.S. Army industrial facilities have resulted in contaminated process equipment, scrap metal, and sewer systems. Because of the residual contamination, these items can not be reused or disposed. The U.S Army Toxic and Hazardous Materials Agency has studied technologies to effectively treat these explosive-contaminated materials. The most promising of these technologies was hot gas decontamination. A recent field demonstration at Hawthorne Army Ammunition Plant demonstrated the ability of the hot gas decontamination system to effectively remove explosives such that the test items are not characteristically hazardous and are appropriate for disposal as scrap. Based upon the success of this demonstration, the Hawthorne Army Ammunition Plant intends to implement this technology in current demilitarization operations. Full-scale operation will begin following completion of several system changes. The results of the field demonstration and the proposed system changes are described.

INTRODUCTION

Each year the Department of Defense must dispose of thousands of tons of energetic material and munitions which are obsolete or unserviceable. The processing of this material is usually accomplished by one of two methods, either reclaiming the energetic material from its casing or through the use of open burning/open detonation. Both of these methods result in contaminated scrap metal or process equipment that cannot be disposed due to the presence of residual energetic materials. These residual explosives, even in trace quantities, poses both a safety and environmental hazard. Because of these problems, the Department of Defense has found itself holding an ever growing stock of contaminated equipment and scrap which it cannot process through normal property disposal channels.

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A number of methods have been employed in an attempt to eliminate this problem, however, none has proven totally satisfactory and effective. The two most common techniques for decontaminating these items has been the use of steam cleaning and fire. Steam cleaning, in most cases, is an effective means of achieving surface decontamination, however, hard to reach areas on complex structures such as demilitarization process equipment are not thoroughly decontaminated. The use of fire typically centers on the use of a flash furnace or burning. In either case, a number of drawbacks can be found in the use of thermal treatments. Both flashing and burning are subject to regulatory requirements since the procedures create air emissions and the public perceives this technology as an incineration technology. The flashing furnace relies on thermal initiation to decontaminate any residual explosives. This procedure results in a surface decontamination and cannot adequately treat the complex surfaces of machinery and process equipment. Incineration is another technology which is capable of complete decontamination, however, it is uneconomical, and destroys the physical structure and inherent value of the contaminated material. Also, the contaminated material must be small enough to fit into the incinerator.

IDENTIFICATION AND EVALUATION OF NOVEL DECONTAMINATION CONCEPTS

In 1982, the U.S Army Toxic And Hazardous Materials Agency (USATHAMA) sponsored a project to offset these problems and develop an effective decontamination procedure suitable for both process equipment and scrap materials. The goal of this project was to identify and evaluate safe decontamination technologies which produce little or no waste while completely decontaminating the energetic materials. The targeted explosives compounds were trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-s-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), di- and tri- nitrobenzene compounds, smokeless powder, and ammonium picrate (Yellow-D). Research efforts were centered on identifying and evaluating technologies that could be applied to a number of structural materials such as metal, concrete, and painted surfaces. Battelle Columbus Laboratories performed an analyses of existing explosives decontamination techniques. Battelle representatives gathered information from government and private sector energetics manufacturers, and visited and analyzed government facilities and equipment contaminated with explosives.

In July of 1983, Battelle completed the analyses of technologies[1]. These technologies were centered on the four main concepts of thermal decomposition, abrasive removal, extraction, and chemical treatment. Each technology was judged based upon the following characteristics; destruction efficiency, mass transfer, safety, damage to exiting structures, applicability to complex surfaces, penetration, operating and capital costs, and waste residue and disposal. A number of combined methodologies were also

considered and evaluated. A total of fifty-six technologies and combined technologies were evaluated. Of these technologies, only six were found to be suitable for further investigation into their potential effectiveness as explosive decontamination scenarios. The six methods selected were hot gas, combined hot gas and chemical pretreatment, vapor circulation, free radical induced decomposition, base initiated decomposition, and sulfur based reduction.

Within the realm of thermal decomposition, the use of hot gases received the highest overall ranking and the most favorable results in all the evaluated categories. The hot gas concept is built upon exposing contaminated items to hot gases in order to volatilize and decompose the contaminant. The resulting stream of hot gases, vaporized explosives, and break down products are then destroyed in an afterburner unit. Burning was regarded fairly well in most categories, but received the lowest possible ratings for safety and structural damage. The only thermal concept recommended for further development was the hot gas process.

LABORATORY TESTING

Having identified six technologies suitable for additional investigation, the program entered a second phase of development which provided more technical data. The laboratory testing was designed to determine each technology's range of applications and efficiency of decontamination[2]. These tests were conducted with coupons that had been spiked with known quantities of 2,4-Dinitrotoluene (DNT), 2,6-DNT, TNT, RDX, HMX, and TETRYL. Coupons composed of steel, concrete, and painted concrete were subjected to the treatment scheme under investigation. After appropriate treatment times the coupons were analytically examined for residual explosives and adverse effects on the coupon material. These tests revealed a number of cases where residual explosive levels were below detection limits. Each technology was found to have its own unique advantages and disadvantages. The widest applicability and greatest degree of decontamination was found with the use of the hot gas system.

A detailed analysis also showed that the hot gas method entailed some potential problems. During laboratory testing it was noted that explosive crystals formed on the outer (uncontaminated) surface of concrete coupons. This formation indicated that the hot gas system caused explosives to migrate through concrete rather than destroying the energetic material. The concrete coupons were also found to be dried out because of the high operating temperature of the hot gas technique. This drying caused a noticeable loss of strength within individual concrete coupons. These problem areas led to further evaluation of chemical pretreatment combined with the hot gas system.

In exploring chemical pretreatment, it was found that the use of caustic chemicals created a situation in which not only lower operating temperatures were used but also quicker destruction times were achieved with the hot gas system. At the same time the quicker destruction and lower temperatures reduced the chances of explosive migration. These findings contributed to the conclusion that the hot gas system, complimented by chemical pretreatment, was clearly the most promising technology to pursue outside of the laboratory and for wide spread application.

HOT GAS DECONTAMINATION OF CONTAMINATED BUILDINGS

After considering a number of potential pilot test sites a projectile washout facility at Cornhusker Army Ammunition Plant (CAAP) was selected for a field demonstration test in 1987[3]. The demonstration was conducted for USATHAMA by Arthur D. Little, Incorporated. The objectives were to determine the full scale effectiveness of the hot gas system (both with and without pretreatment), provide full scale design criteria, and data for regulatory permitting. The CAAP facility measured approximately twenty-five feet long by twenty-five feet wide and eleven feet high. The demonstration area was divided by constructing a wall and false ceiling to provide two distinct areas in order to pretreat one area with caustics (a solution of sodium hydroxide and dimethylformamide). The TNT concentration in the building was too low to properly challenge the hot gas methodology so contaminated concrete blocks (from a sump) were placed in the test areas.

Hot gases were pumped into the building through duct work from a 3 million btu/hour propane fired burner. The resulting gas stream was than collected and exited the building through a propane fired afterburner. The gas streams entering and exiting the building, and exiting the afterburner were carefully monitored and analyzed. Additionally, thermocouples were employed to monitor and record the temperature profiles of building materials, and inside the building. Concrete samples were mechanically tested both before and after the hot gas treatment.

The evaluated data from the CAAP test indicated that the hot gas system was both safe and feasible. Although the pretreatment with caustics was effective in increasing surface explosives removal, the effects of the hot gas stream alone provided the bulk of interior explosives removal and decontamination. The mechanical testing of concrete samples revealed an average compressive strength loss of five percent while tensile strength losses averaged between twenty and thirty percent. These effects imply that the age and style of concrete construction should be considered when designing individual hot gas system applications.

DEMONSTRATION ON EXPLOSIVES CONTAMINATED EQUIPMENT

In 1989, a pilot-scale test was conducted by Roy F. Weston Inc., to expand the understanding of the hot gas system and its applications to explosives contaminated equipment[4]. The demonstration was conducted at the Hawthorne Army Ammunition Plant (HWAAP), Hawthorne, Nevada. The HWAAP tests were designed to examine the ability of the hot gas system to decontaminate process equipment and known structural materials such as vitrified clay, copper, and aluminum. The list of evaluated contaminants was also expanded to include nitroglycerine, nitrocellulose, and ammonium picrate. An existing flashing chamber at HWAAP was modified to utilize the same burner and afterburner from the CAAP test. A process diagram is provided in figure 1. This modified chamber was than used to treat materials selected from the large stock of contaminated equipment and munitions items held at the HWAAP. Vitrified clay materials were taken from the highly contaminated piping system at the West Virginia Ordinance Works.

Prior to treatment all materials were sampled to determine the extent and quantity of contamination and instrumented with thermocouples to monitor temperature profiles. The items were then placed on a large cart and placed in the flashing chamber. Following treatment the items were subjected to surface wipes and solvent rinses to sample for residual explosives contamination. The tests revealed that treatment at 500 degrees fahrenheit for twelve hours successfully decontaminated the surfaces and interior of intricate process equipment of all tested materials. Based on the results of this field demonstration, the hot gas decontamination technology is ready for full-scale implementation. Several modifications were identified which make this process economical.

TECHNOLOGY TRANSFER

The Hawthorne Army Ammunition Plant is currently implementing several of the design modifications identified in the previous field demonstration to the hot gas decontamination system at HWAAP. These changes should improve the performance and economics of the decontamination system. The air preheater and afterburner are being modified to operate on diesel fuel (DF2) instead of propane. A recirculation system is being designed to permit the use of the afterburner exhaust gases to preheat the air entering the air preheater. The retrofited flashing chamber has been insulated to prevent the thermal energy loss through the concrete walls. These modifications are nearly completed and the State of Nevada has issued an operating and air quality permit for the operation of this system. Another set of tests are scheduled in the near future to identify the benefits of these new modifications and determine the full scale operating parameters.

REFERENCES

1. Benecke, H. P., Zemeju, E. R., Nixon, J. R., Garrett, B.C., Carlton, P. J., Gaughan, P. J., Graham, S. M., Hallowell, J. B., Vanek, D. G., Vutatakis, D. G., and E. J. Mezey, "Development of Novel Decontamination and Inerting Techniques for Explosives-Contaminated Facilities, Phase I - Identification and Evaluation of Novel Decontamination Concepts", U.S. Army Toxic and Hazardous Materials Agency, Report No. DRXTH-TE-CR-83211, Aberdeen Proving Ground, Maryland, July 1983.

2. Hopper, D. R., Benecke, H. P., Mezey, E. J., and S. C. Lugibihi, "Development of Novel Decontamination and Inerting Techniques for Explosives-Contaminated Facilities, Laboratory Evaluation of Concepts, Phase II - Laboratory Evaluation of Novel Explosives Decontamination Concepts, U.S. Army Toxic and Hazardous Materials Agency, Report No. DRXTH-TE-CR-85009, Aberdeen Proving Ground, Maryland, July 1985.

3. Woodland, L.R., Balasco, J. W., Adams, K. J., Beltis, K. J., Kleinschmidt, D. E., Randel, M. A., Rosetti, M., and K. E. Thrun, "Pilot Plant Testing of Caustic Spray/Hot Gas Building Decontamination Process", U.S. Army Toxic and Hazardous Materials Agency, Report No. AMXTH-TE-CR-87112, Aberdeen Proving Ground, Maryland, August 1987.

4. Mazelon, M., Johnson, N., Cosmos, M. and P. Marks, "Task Order, Pilot Test of Hot Gas Decontamination of Explosives-Contaminated Equipment at Hawthorne Army Ammunition Plant (HWAAP) Hawthorne, Nevada, U.S. Army Toxic and Hazardous Materials Agency, Report No. CETHA-TE-CR-90036, Aberdeen Proving Ground, Maryland, July 1990.

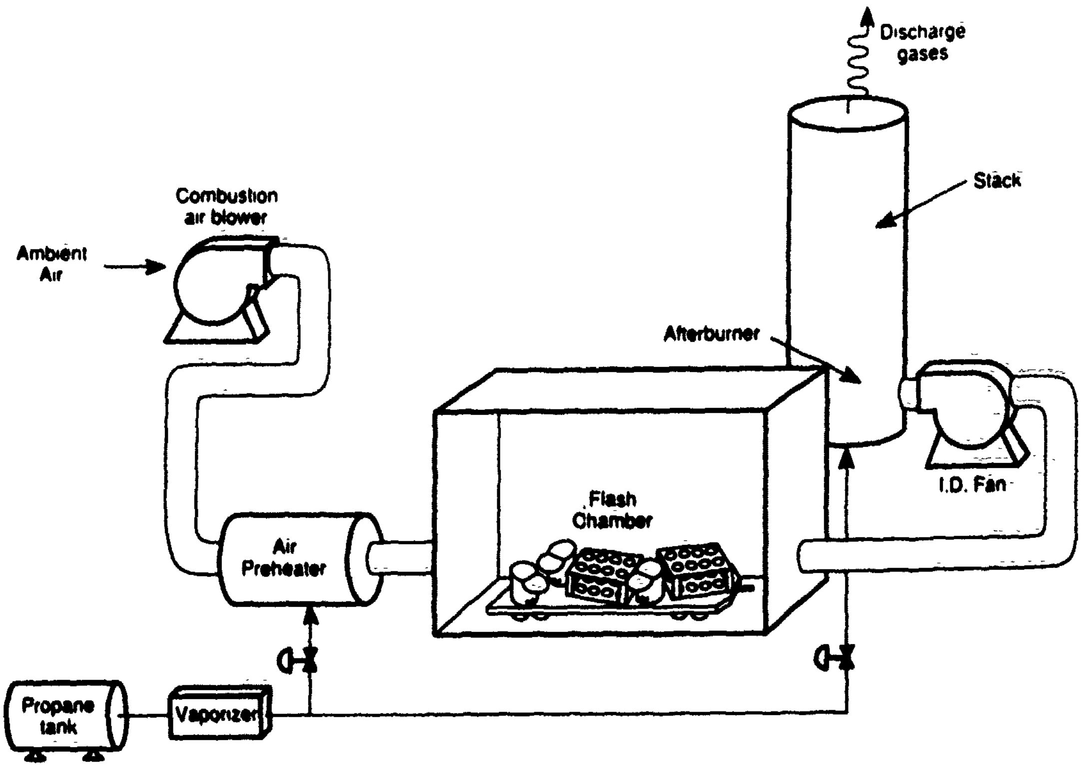

Figure 1
Hot Gas Decontamination Process Schematic

Decontamination of Chemical Agent Contaminated Structures and Equipment

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ABSTRACT

Operations involving chemical agents such as manufacture, loading, storage, and demilitarization have resulted in the contamination of buildings and a wide variety of processing equipment. The contamination has been caused by a number of chemical agents with the most persistent being mustard. Materials that are contaminated include concrete (in floors and walls), metals (in piping, and process equipment), and wood. All of these materials exist in both painted and unpainted forms.

Many of the contaminated facilities have potential reuses or monetary value as excess property if they can be properly decontaminated. Much of the contaminated process equipment also has monetary value as scrap material if properly decontaminated. Currently this value can not be realized since the only acceptable decontamination method involves destruction and incineration of the contaminated material.

Past efforts at resolving this situation have identified some 56 concepts which could be utilized with five having been evaluated under laboratory conditions. These concepts include thermal, abrasive, chemical, and extractive removal schemes. Each of these technologies was evaluated based on destruction efficiency, mass transfer, safety, damage to existing materials, penetration depth, applicability to complex surfaces, cost, and waste management. Based on these comparisons hot gas technology was identified as the most suitable methodology.

Currently a full scale demonstration is in the design phase for implementation at Rocky Mountain Arsenal. The chosen site was originally contaminated with mustard and mustard degradation by-products from past demilitarization activities. The building contains concrete approximately eighteen inches thick, large metal storage tanks, process piping, motors, and pumps.

INTRODUCTION

The Department of Defense owns a large inventory of real property and process equipment which has been operationally contaminated by chemical warfare agents. Typically this

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contamination has been the result of manufacturing or demilitarization operations at military industrial complexes. The contaminated material and equipment has always been radiply decontaminated to a 3X status, which indicates surface decontamination but no action for agents which might have penetrated into the material. This doubt has meant that 3X certified materials can not be released from government control without being processed to attain a 5X rating. The only currently accepted method of attaining a 5X status is to expose the item to 1000 degrees F for fifteen minutes. This requirement requires that complex or large items must be dismantled prior to treatment and the thermal extremes also physically alter many materials and reduce the value of the excess property.[1] Also, since this is an operational scenario and not an analytically established standard the release of the treated material is not assured. Prior to the end of the Cold War, and the accompanying shift in the World political order, this glut of excess property could be accepted, but with the shift to a smaller military excess non-productive property can no longer be tolerated.

Current Decontamination Methods

A number of methods have been employed in attempts to eliminate this problem, however, none has proven totally satisfactory and effective. The most common technique has been the use of fire. The use of fire typically centers on the use of a flash furnace or burning. In either case a number of drawbacks can be found in these thermal treatments. Both flashing and burning can be subjected to regulatory requirements since the procedures create air emissions and public opinion could prevent efficient operations if perceptions of thermal treatment as incineration arise. The flashing furnace relies on thermal initiation to decontaminate any residual agents. This procedure again results in a surface decontamination and cannot adequately treat complex surfaces or machinery. In the case of burning complete decontamination occurs but the physical structure and inherent value of the contaminated material is altered resulting in the government realizing a lower value for the recovered scrap.

Novel Decontamination Concepts Development

In 1982 the U.S Army Toxic And Hazardous Materials Agency (USATHAMA) started a project to offset these same problems for items contaminated with energetics. The energetics oriented project was aimed at developing an effective decontamination procedure suitable for both process equipment and scrap materials. The goal of this project was to develop a safe decontamination technology which produces little or no waste while completely removing energetic materials from complicated items. Typical compounds targeted for removal were military explosives such as

trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-s-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), di- and tri- nitrobenzene compounds, smokeless powders, and ammonium picrate (Yellow-D). Research efforts were centered on developing a technique that could be applied to a number of structural materials such as metal, concrete, and painted surfaces. This capability provided for the secondary goal of being able to apply the emerging technology not only for process equipment and scrap material but also to large structures. This alternative provided the first indication novel approaches could be applied to the problem of dealing with 3X rated chemical agent facilities and equipment.

The initial stage of the energetics development program required a review of existing methodologies and any novel methods. Battelle Columbus Laboratories was awarded a contract to perform an analysis of existing explosives decontamination techniques and develop descriptions of emerging concepts. Battele representatives gathered information from government and private sector energetics manufacturers as well as visiting and analyzing government facilities and equipment contaminated with explosives. In July of 1983 Battelle provided a report detailing the analysis of the technologies. These technologies were centered on the four main concepts of thermal decomposition, abrasive removal, extraction, and chemical treatment. Each technology was judged based upon the following characteristics; destruction efficiency, mass transfer, safety, damage to exiting structures, applicability to complex surfaces, penetration, operating and capital costs, and waste residue and disposal. A number of combined methodologies were also considered and evaluated. At the same time the similarities between the energetics and agent contamination problems indicated that the same results were possible for an agent oriented decontamination system. This possibility led to the Battelle Columbus Laboratories being contracted to evaluate novel agent decontamination procedures. The evaluated technologies (refer to Table 1) focused on the same areas and criteria used in developing the energetics decontamination system.

Within the realm of thermal decomposition the use of hot gases received the highest overall ranking and favorable results in all the evaluated categories. The hot gas concept is built upon exposing contaminated items to hot gases in order to volatilize and decompose the contaminant. The resulting stream of hot gases, vaporized agents, and break down products are then destroyed in an afterburner unit. Burning was regarded fairly well in most categories but received the lowest possible ratings for safety and structural damage. The flashblast process was found to be highly effective as a surface decontamination system and was recommended for evaluation as a complimentary element in a combined technology.

All of the abrasive removal methods were rejected for further development, largely because of the high costs of waste stream treatment and disposal. These concepts also were deemed to be

unacceptable because of their relatively shallow penetration depth (without causing physical damage).

In terms of extractive removal, external steam generation was evaluated with high scores. This system involves the pumping of steam into the contaminated structure, or equipment, to purge the contamination. Freon vapor circulation was also judged to merit further development.

Of the chemical treatment technologies three were found to be suitable for further development. The concepts chosen were N-Octyl-pyridinium 4-aldoxime bromide (OPAB) solution, Monoethanolamine (MEA) solution, and ammonia gas.

TABLE 1: Evaluated Technologies

	Thermal Decomposition	
Flashblast	Contact Heating	Hot Plasma
Microwave Heating	Infrared Heating	Hot Gases
Solvent Soak/Burn	Flaming	CO_2 Laser
Burning		
	Abrasive Removal	
Electropolishing	Acid Etch	Scarifier
Sandblasting	Demolition	Drill and Spall
Ultrasound	Cryogenics	Hydroblasting
Vacu-blast		
	Extract Removal	
Solvent Circulation	Supercritical Fluids	Ultrasonic
Surfactants	Strippable Coatings	Manual Steaming
External Steam Generator	Vapor Phase Solvent Extraction	
	Chemical Treatment	
STB	Base Initiated Decomp.	Decomp. W/ DS2
Molten Decomposition	Microbial	Sodium Borohydride
Sulfur Based Reduction	Reduction Cleavage	Reactive Amines
Ultraviolet	Gamma Radiation	Chromic Acid
Ozone	Ascorbate	Gels
Foams	Chlorine/Chlorite	Ligands
Hydrolysis	Enzymes	

A total of sixty-five technologies and combined technologies were evaluated and considered for further development. Of these technologies six (see table 2) were found to be suitable for further investigation.

Table 2: Phase 2 Technologies

Hot Gases
External Steam
OPAB
MEA
Freon Vapor Circulation
Ammonia Gas
Flashblast (Complimentary to One of The Above)

Laboratory Testing

Having found six technologies suitable for additional investigation the program entered a second phase of development which provided more detailed analysis. The most important aspect of this phase was the laboratory testing designed to determine the range of applications and efficiency of decontamination. The laboratory testing was directed at determining the evaluated technology's effectiveness to decontaminate structural materials (both painted and unpainted)such as mild steel, stainless steel, concrete. The testing utilized measured GB, VX, and HD contamination to determine effectiveness. These tests revealed a number of cases where residual agent levels were below detection limits and each technology was found to have its own unique advantages and disadvantages. The widest applicability and greatest degree of decontamination was found with the use of the hot gas system. Steam extraction was also found to provide a high degree of application and agent removal. These two systems were subjected to a detailed engineering and economics analysis which suggested that both methods were feasible but that in terms of overall costs the hot gas process should be pursued.

Detailed analysis during the energetics evaluation also showed that the hot gas method entailed some unique features. During laboratory testing it was noted that explosive crystals formed on the outer (uncontaminated) surface of concrete coupons. This formation indicated that the hot gas system caused explosives to migrate through concrete rather than destroying the energetic material. Since chemical agents had previously been found to be reactive with concrete this hot gas induced diffusion was thought to be an effective means of removing these breakdown products. The energetic spiked concrete coupons were also found to be dried out because of the high operating temperature of the hot gas technique. This drying caused a noticeable loss of strength within individual concrete coupons which implied that the hot gas system would require tailoring to specific facilities and conditions.

Pilot Test

In order to evaluate the hot gas concept on a large scale a

pilot test was conducted by Battele Laboratories at Dugway Proving Ground in 1987. Dugway Proving Ground was chosen because of its ability to provide test chambers that provided environmental control, containment, and the possibility of remote operations. The pilot test was centered on the full scale ability of the hot gas process to remove a controlled amount of HD (earlier studies had proven Mustard to be one of the most persistent and widespread contaminants) typical building and equipment materials. The test was conducted within a chamber containing walls made from poured concrete, concrete blocks (both solid and hollow), and mild steel. These materials were initially spiked with known concentrations of HD and then subjected to incremental heating until ambient temperatures reached 750 degrees F. This condition was maintained for one hour and then a cool-down period was instituted (approximately 38 hours reach temperatures below 100 degrees F). Air monitoring equipment indicated that agent volatilization began almost immediately and reached a peak approximately 40 minutes after reaching 750 degrees F. Analysis of the test structures also revealed that no HD residuals existed above the detection limit (verified to be 500 parts per billion) after exposure to the hot gas process. Overall the lot test served to demonstrate the effectiveness of the hot gas system and that engineering requirements had been sufficiently identified to move on to full scale field demonstration. Additionally, the pilot test demonstrated the fact that portable heating units could be used in the field and that the tailoring requirement identified in the energetics development could be met.

Field Demonstration

Currently a full scale field demonstration is scheduled to begin in February 1993 at Rocky Mountain Arsenal. The selected test structure, the thaw pit contained in Building 537, was contaminated during the loading and demilitarization of H and HD munitions. The pit area is composed of concrete walls and floors (approximately eighteen inches thick) and steel piping and process equipment. The full scale demonstration equipment is currently being designed and sized for installation in the December time frame.

Available Documentation

1. Final Technical Report: Development of Novel Decontamination and Inerting Techniques for Explosives-Contaminated Facilities, Phase I - Identification and Evaluation of Novel Decontamination Concepts, USATHAMA Report DRXTH-TECR-83211, July 1983.

2. Final Technical Report: Development of Novel Decontamination and Inerting Techniques for Explosives-Contaminated Facilities, Laboratory Evaluation of Concepts, Phase II - Laboratory Evaluation of Novel Explosives Decontamination Concepts, USATHAMA Report

AMXTH-TE-TR-85009.

3. Final Report: Development of Novel Decontamination Techniques For Chemical Agents (GB, VX, HD) Contaminated Facilities, USATHAMA Report AMXTH-TE-TR-85012, June 1985.

4. Final Technical Report: Decontamination of the Hot Gas Decontamination System For Chemical Agents, Task 3, USATHAMA Report CETHA-TE-CR-89168, August 1989.

5. Final Report: Contamination Assessment Report, Building 537, Rocky Mountain Arsenal, Colorado, USATHAMA Report CETHA-TE-CR-89167, June 1989.

CAMP STANLEY
UNDERGROUND MAGAZINE DESIGN VALIDATION TEST

Twenty-Fifth DOD Explosives Safety Seminar
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INTRODUCTION

Various units of the U.S. Eighth Army's 2nd Infantry Division, located just south of the DMZ in Korea, maintain basic operating loads of ammunition at Ammunition Holding Areas, or "AHA's," located within the boundaries of their camps. In the past, these AHA's have been exempted from the normal Quantity-Distance, or "Q-D," safety hazard ranges established by the DOD Explosives Safety Board (DDESB), because of the transcendent need for the units to have immediate access to their munitions in the event of a combat emergency.

An underground munitions storage facility (Figure 1) has been designed as an alternative to the open storage currently used at Camp Stanley, to provide reduced hazard distances and increased security. The facility will provide 22 parking bays (eight in the first phase of construction which was completed this year, and 14 in the second phase, yet to be constructed). Each bay will accommodate two ammo trucks. Each truck will be uploaded with a unit basic load of artillery ammunition, with a potential maximum of 10,000 pounds Net Explosive Weight (NEW) per truck, or 20,000 lb per bay.

Typical underground munitions storage facilities do not accommodate uploaded vehicle storage. Because the Camp Stanley facility is unique in design, no data exists to indicate that an accidental explosion of the ammo in one bay will not propagate to adjacent bays. Therefore, the DOD Explosives Safety Board requires use of the entire NEW (440,000 lb) capacity of the facility as the Maximum Credible Event (MCE) in hazard range (Q-D) calculations. The Board will, however, allow a reduced MCE when data are shown to support a reduction.

The Camp Stanley Munitions Storage Magazine Validation Test, described in this paper, was designed to evaluate the risk that a detonation of 20,000 lb NEW in one bay would propagate to adjacent bays. If the test results show that a detonation will not propagate, then the explosives safety Q-D can be reduced to that required for the NEW of a single bay. It was determined that a 1/3-scale experiment, simulating an accidental detonation in the Stanley facility, would be large enough to provide meaningful results, yet small enough to be an affordable test.

The basic test program was funded by the U.S. Eighth Army. Additional funds were provided by the KLOTZ Club to acquire additional airblast and ground shock diagnostic measurements. The KLOTZ Club is an international organization of seven countries (France, Germany, Norway, Sweden, Switzerland, the United Kingdom, and the United States) which cooperatively support safety research for underground ammunition storage.

This paper describes the technical data acquired in the 1/3-scale test to validate the Camp Stanley underground magazine design, and presents a comprehensive analysis of (a) the risk of a detonation propagation within the Camp Stanley facility, and (b) the Q-D area recommended for the facility.

OBJECTIVE

The objective of this test program was to evaluate the potential for sympathetic detonation (by prompt communication) of munitions in adjacent storage bays (the acceptors) from an accidental detonation in one bay (the donor) of the Camp Stanley underground magazine.

DESCRIPTION OF TEST

The Camp Stanley Concept Validation Test Program consisted of three high explosive detonations (10.7, 57.9 and 336.0-kg Composition B charges) simulating, at 1/3-scale, accidental explosions of ammunition stored on vehicles in parking bays (or adits) of an underground storage complex in granitic rock. The two smaller charges were for calibration tests, and the large charge simulated the full 20,000-lb NEW of a full-scale storage bay. The 1/3-scale storage bays were constructed to be 6 m long (along centerline), 3.7 m wide and 2.1 m high. The access tunnel was 54 m long, 2.1 m wide, and 2.1 m high. Longitudinal tunnel/adit cross-sections are shown in plan and profile in Figure 2. Internal airblast pressure and thermal (temperature and flux) measurements were made in the access tunnel and acceptor adits. Free-field airblast pressure measurements were made along the extended tunnel centerline outside the portal and on the overburden above the tunnel. Surface ground motions were recorded on the overburden above the tunnel and donor adit.

DONOR AND ACCEPTOR CHARGES

The 336.0-kg donor charge for the main test was packed in a plywood container and placed in the middle (donor) adit on the rear of a M151 jeep (Figure 3). The interior charge container dimensions were 76.2 by 76.2 by 68.9 cm high. The container

was positioned on the chamber centerline with the center 1.5 m from the rear wall of the adit. The approximate chamber loading density was 11.1 kg/m^3. Sixty-five inert 40mm projectiles were placed on the fire-wall of the jeep to simulate the debris hazards from unexploded munitions.

To determine the effect of the main detonation on explosive and flammable materials in bays adjacent to the donor bay, representative items were placed in the two acceptor adits on the 1/3-scale test (Figure 4). These materials represented a variety of Hazard Class 1.1, 1.2, and 1.3 materials, including bulk explosives (10 kg of Comp B in two light metal containers), diesel fuel (10 liters in a light metal gas can), boxed 105mm artillery munitions (three boxes of Comp B-filled C445 projectiles with propellant charges), palletized 155 mm projectiles (eight M107 rounds) and propellant charges (eight D541 canisters).

INSTRUMENTATION

The instrumentation program was subdivided into four study areas: internal airblast (tunnel and storage adits), internal thermal effects (temperature and thermal flux), external airblast, and ground motion. The internal airblast and thermal measurements provided essential data for evaluating the risk of sympathetic detonation of materials in the acceptor adits, and provided additional data for further development of airblast prediction theories for accidental detonations in underground magazines. The free-field airblast and ground motion measurements also provide quantitative data to establish hazard ranges.

A total of 25 transducers (13 side-on and 4 stagnation pressure, 5 thermal flux and 3 thermocouples) were installed inside the tunnel and storage adits. Side-on overpressure measurements were made at the entrance to the donor adit (at the juncture with the tunnel wall and in the center of the tunnel), in the center of the acceptor adits, and at nine selected points along the centerline of the access tunnel. Stagnation pressure gage mounts were installed at one point in the rear of the tunnel and at three points between the first acceptor adit and the tunnel portal. The stagnation pressure gages were add-on measurements funded by the KLOTZ Club. Five thermal flux sensors were installed, one in the center of each acceptor adit, one in the rear of the tunnel, and two between the first acceptor adit and the tunnel portal. The locations of the internal instrumentation are shown in Figure 5 (plan view).

A total of 19 gages (7 side-on, and 3 stagnation pressure, and 9 accelerometers) were installed outside the tunnel. Side-on and stagnation pressure measurements were made at ranges of 5, 10, and 25 m from the tunnel entrance to establish flow and dynamic pressure levels along the extended tunnel centerline. Each stagnation gage was mounted on a steel gage mount 75 cm above the ground surface, with a flush-mounted

side-on pressure gage immediately below. All other free-field gages were flush-mounted on the ground surface for side-on measurements. The gage distances were measured from the tunnel portal. Free-field airblast gage locations are shown in Figure 6.

DEBRIS COLLECTION

The objectives of the fragment collection portion of the test program was to determine the distribution of metal fragments inside the acceptor adits and in the free-field outside the tunnel portal. Two sources of fragments were of interest; those produced by the breakup of the jeep on which the explosive charge rested, and those from the inert 40mm rounds placed upon the front of the jeep. The collection effort consisted of visually searching the acceptor adits for any metallic fragments and a survey of the area outside the tunnel to record the position (angle and distance) of all pieces recovered.

RESULTS

Peak overpressures measured in the tunnel and acceptor adits are plotted versus distance (from the donor charge initiation point) in Figure 7. A comparison is shown with the airblast pressure predictions computed using the DDESB exit pressure criteria. Although, again, there is considerable data scatter, a least squares fit of the measured pressures in the acceptor adits indicate that the measured pressures were about one-half of the predicted values.

Figure 8 shows a comparison of measured and predicted peak stagnation pressures. The measured peak stagnation pressure was relatively uniform throughout the tunnel. A comparison of the peak internal pressures (side-on and stagnation) from Figures 7 and 8, respectively, is presented in Figure 9. Although there is significant data scatter, these measurements indicate that the pressures flowing to the rear of the facility were approximately half the pressures flowing to the portal.

Peak airblast impulse levels measured in the tunnel are plotted versus distance from the donor charge in Figure 10. A least squares data fit is included for the "to portal" data (i.e., the measurements between charge adit and the portal). It is significant to note, as shown in this plot, that the peak impulse levels in the acceptor adit were comparable to the values obtained in the tunnel, and not a factor of two less as was noted for peak pressures.

A comparison of predicted and measured peak external overpressures along the extended tunnel centerline (0-degree azimuth) is presented in Figure 11. Reasonable agreement is shown between the measured data and the the elvels predicted by the

formula given for Inhabited Building Distance in the DOD Ammunition and Explosives Safety Standards (6055.9-STD). A similar comparison between the measured peak free-field pressures (side-on and stagnation) versus range in the vicinity of the tunnel (25-m radius) is plotted in Figure 12. Although there is some scatter, the predicted values for side-on pressure provide a reasonably good estimate for the measured data. However, the predicted stagnation pressure curve falls significantly below the measured data. Stagnation pressure is the sum of the side-on and dynamic pressure, and dynamic pressure is a function of the shock velocity squared. Therefore, higher measured stagnation pressures imply that the spherically expanding blast wave has a higher shock velocity than is predicted by computer moels such as CONWEP (Hyde, 1988). This is an indication that significant jetting of the detonation gases extends outside the tunnel portal.

DEBRIS HAZARDS

The munitions placed in the acceptor adits appeared to have easily survived the detonation of the 336-kg Comp B donor charge. The post-detonation damage to munitions in Acceptor Adit A is shown in Figure 13. The artillery articles were thrown to the rear of the adit with only minor damage resulting. Several of the 155 mm propellant containers sustained buckling damage, similar to that seen in the left center of Figure 13. This damage appears to be associated with shock loading, rather than any form of impact. No debris fragments were found in either acceptor adit. No indication was seen of any debris impact on any of the munitions placed in these adits. The debris hazard within the main tunnel is graphically depicted in Figure 14, which shows a section of the jeep that was blown against, and caught by, one of the stagnation pressure mounts. The containers of diesel fuel placed in the acceptor adits were empty. Since there were no evidence of burning in the acceptor adits, it is assumed that the diesel fuel leaked out following shock loading of the containers and was absorbed in the loose rock of the adit floor.

The locations of metal debris (pieces of 40-mm projectiles and jeep) thrown beyond the tunnel portal were surveyed after the test. In Figure 15, the debris distances from the portal are plotted versus the horizontal angle (measured clockwise from the extended centerline of the access tunnel) to the debris location. The debris distribution was, to some degree, limited by the site topography. A relatively level bench immediately outside tunnel portal extended approximately 30 m over an arc (measured from the extended tunnel axis) from +5° to -90°. This surface was constructed from the spoil material from the underground excavation, and the slopes at the edge of the bench were steep (at or near the angle of repose for broken rock). This accounts for the scarcity of fragments found at negative angles between distances of 30 and 50 m.

Fragments found beyond 70 m were located in a grove of Aspen trees, which retarded further travel.

The external fragment collection area was subdivided into collection zones 10 m long (radially) by 5° of arc (or +/- 2.5°) for analysis purposes. The total fragment density measured for each collection zone was used to calculate the number of fragments per 56 m^2 of area. This density is plotted versus distance from the portal (to the center of each collection area) in Figure 16. Total density is defined as the number of fragments landing in a collection zone, plus all the fragments falling in the sector beyond the specified collection zone, with the total number of fragments divided by the total area of the zone. As seen in Figure 16, the longer-range fragment distances were limited by terrain and trees, as indicated by the down-turn of the distribution curves at 65 m and beyond. However, the fact that the deposition points of the long-range fragments was well below the elevation of the tunnel portal indicates that these fragments would not have traveled significantly farther over level terrain.

AIRBLAST HAZARD ANALYSIS

For the long, "U"-shaped tunnel layout of Camp Stanley, an accidental detonation in a storage adit near a portal will produce a high-pressure shock wave at the nearest portal, and a lower pressure at the farther portal. The time lag between the shock waves exiting the two portals is such that there will be little interaction of the external shock fronts. Actually, the maximum Inhabited Building Distance (IBD) will result from detonations in the storage adits at the rear of either tunnel leg. Shock waves generated by such detonations will arrive at both portals almost simultaneously, resulting in maximum interaction and reinforcement of the external (free-field) shock front outside the portals. A prediction of the far-field pressures under these circumstances is very difficult. The IBD contour shown in Figure 17 was computed by assuming a compounding of the two wave fronts as the limiting upper bound value. Thus, the computed effective exit pressure used to calculated the IBD range was essentially doubled (compared to the exit pressures normally calculated for single-entrance tunnels). As shown in Figure 17, the IBD (to the 8.3-kPa pressure level) was 438 m from the right portal and 435 from the left. The curved egress sections near the tunnel portals are designed to direct the airblast axis away from the inhabited areas of Camp Stanley.

DEBRIS HAZARD ANALYSES

Figure 18 summarizes the predicted external fragment/debris hazard for the Camp Stanley facility. The total fragment density data plotted in Figure 16 is scaled by

dividing the distance from the portal (R) by the one-sixth power of the explosives charge loading (Q) in Figure 18. An upper bound line is drawn as a means of estimating the Q-D for debris (one fragment per 56 m^2), assuming a log-log linear decay in fragment density. The estimated Q-D obtained in this manner is 100 $m/kg^{1/6}$. Thus, the estimated Q-D for a 20,000-lb NEW detonation in the Camp Stanley full-scale facility is 456.8 m.

SYMPATHETIC DETONATION ANALYSES

In Figure 19, the peak overpressures measured in the 1/3-Scale Camp Stanley Validation Test tunnel and acceptor adits are plotted versus distance from the charge detonation point. The distances are multiplied by the scale factor to provide an estimate of overpressures in the prototype facility. The estimated threshold for sympathetic detonation by blast pressure and impulse was developed from previous tests conducted by U.S. Army Ballistic Research Laboratory (BRL) (Collis, 1992), in which 155-mm M107 projectiles were placed at different distances from a 227-kg TNT sphere detonation. Since none of the rounds were sympathetically detonated in the BRL test, including those only one metre from the charge, the assumed threshold for this round is defined as the overpressure and impulse values at a range of one metre from a bare 227-kg (500-lb) TNT hemispherical surface charge detonation. The overpressure predicted by CONWEP (Hyde, 1988) for this distance from such an explosive charge is 22.15 MPa. As shown in Figure 19, peak overpressures measured in the acceptor adits on the Validation Test were a factor of two less than overpressures measured in the main tunnel, and an order of magnitude lower than the calculated pressure threshold for sympathetic detonation.

Peak impulse values for the 1/3-scale tunnel and acceptor adits were obtained from integrations of the measured over-pressure time histories. The peak impulse values and corresponding distances from the explosive source were multiplied by the scale factor (3) to convert to prototype values, and are plotted in Figure 20. A comparison between the integrated measured data and the estimated impulse threshold for sympathetic detonation (3189 kPa-msec) is presented in Figure 20 (Note - the impulse threshold was also based on the BRL test described above; i.e, the impulse at 1 m from a 225-kg TNT charge detonation). A least-squares-fit to the entire data set, with (99 percent) confidence limits, is included for comparison in Figure 20. Although the impulse data exhibits considerable scatter, the analysis indicates that the probability of the impulse exceeding the estimated threshold for sympathetic detonation is less than one percent.

SUMMARY OF FINDINGS

The airblast instrumentation used to assess the blast hazard from the 1/3-Scale Camp Stanley Underground Munitions Storage Facility Concept Validation Tests provided extensive and consistent data. Internal total pressures of approximately 2.5 MPa measured along the tunnel axis indicate a strong flow or jetting within the access tunnel. Free-field total- pressure measurements along the extended tunnel axis indicate that flow pressures ranged from 2.3 to 4.5 times the peak overpressure over a distance of 5 to 25 m from the portal.

The formula for Inhabited Building Distance given in the DOD Explosives Safety Standards (6055.9-STD, Rev 4) provides reasonable predictions of external airblast overpressures. The effective exit pressure predicted by the Standards is 1.48 MPa, which is 45 percent greater than the measured pressure of 1.02 MPa. However, the exit pressure calculated by this method provides a reasonable (but conservative) basis for developing the free-field airblast prediction. In addition, the peak airblast pressures measured on the test, along with computed impulse values, are in good agreement with the azimuth decay factor used in this relation.

The terrain in the 1/3-scale test area limited the distances over which free-field (external) airblast instrumentation was placed from the portal. Therefore, the only data available to evaluate the Inhabited Building Distance predicted by the Standards is from a combination of close-in airblast and long-range noise pressure measurements. These data indicate that the Standards yield a realistic, but possibly somewhat conservative estimate of the actual airblast Inhabited Building Distance.

Scaled to prototype values, peak overpressures in the acceptor adits were a factor of two less than overpressures at comparable distances in the access tunnel, and a factor of seven less than the estimated overpressure threshold for sympathetic detonation. The peak impulse values show considerable scatter, but were roughly the same in the access tunnel and the acceptor adits. An impulse data least-squares fit, with confidence limits, indicates that the estimated peak impulse threshold for sympathetic detonation falls outside the 95 percent confidence limit.

No fragments were found in either acceptor adit. Limited ejecta data indicated that the free-field fragment hazard is confined to a 30-degree sector along the extended tunnel centerline. An extension of the upper-bound ejecta line provides an estimated hazardous fragment distance of 458.8 m.

CONCLUSIONS

- The empirical relations given in the DOD Standards (DOD 6055.9-STD, Rev 4) for effective exit pressure and Inhabited Building Distance provide good predictions of external airblast from an internal explosion in the Camp Stanley facility.

- The predicted prototype airblast overpressures are well below the estimated overpressure threshold for sympathetic detonation. Confidence limits for the prototype airblast impulse indicates a probability greater than 99 percent that the critical impulse threshold for sympathetic detonation will not be exceeded for the NEW's planned for the Camp Stanley facility.

- The debris data collected from the 1/3-scale Camp Stanley Validation Test indicates that Q-D for hazardous debris will not be exceeded.

RECOMMENDATIONS

Additional data are needed to evaluate the effect of storage loading density on external hazard distances for ground shock and debris. Existing empirical relations overestimate these hazards for low loading densities. In addition, recent work in Sweden indicates that the distances to which debris was thrown out the access tunnel on the Tunnel/Chamber test could be reduced by a debris trap outside the tunnel portal. Further study is needed to evaluate such methods, and their most effective design, to reduce the external debris hazard.

ACKNOWLEDGEMENT

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REFERENCES

Collis, David L., 1992, "Hazard Control Test Results," NMT/TERA NO. T-92-1855-U, New Mexico Institute of Mining and Technology/TERA Group, Socorro, NM.

Department of the Army, 1986, "Fundamentals of Protective Design (Non-Nuclear)," TM 5-855-1, Headquarters, Department of the Army, Washington, D.C.

Department of Defense, 1990, "Ammunition and Explosives Safety Standards," DOD 6055.9-STD, Assistant Secretary of Defense (Manpower, Installations, and Logistics), Washington, D.C.

Hill, John L., III, and Shellum, Colin J., 1991, "Results of a Field Investigation of the Rock Mass Characteristics of the U.S. Army, Corps of Engineers Scaled-Test Tunnel in the Silver Creek Mining Area of Colorado," UTD, Incorporated, Newington, VA.

Hyde, David W., 1988, "User's Guide for Microcomputer Programs CONWEP and FUNPRO, Applications of TM 5-855-1, "Fundamentals of Protective Design for Conventional Weapons," Instruction Report SL-88-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

UTD Incorporated, 1992, "Final Report, Analysis of Rock Mass Behavior of the Camp Stanley Validation Test," UTD Incorporated, Newington, VA.

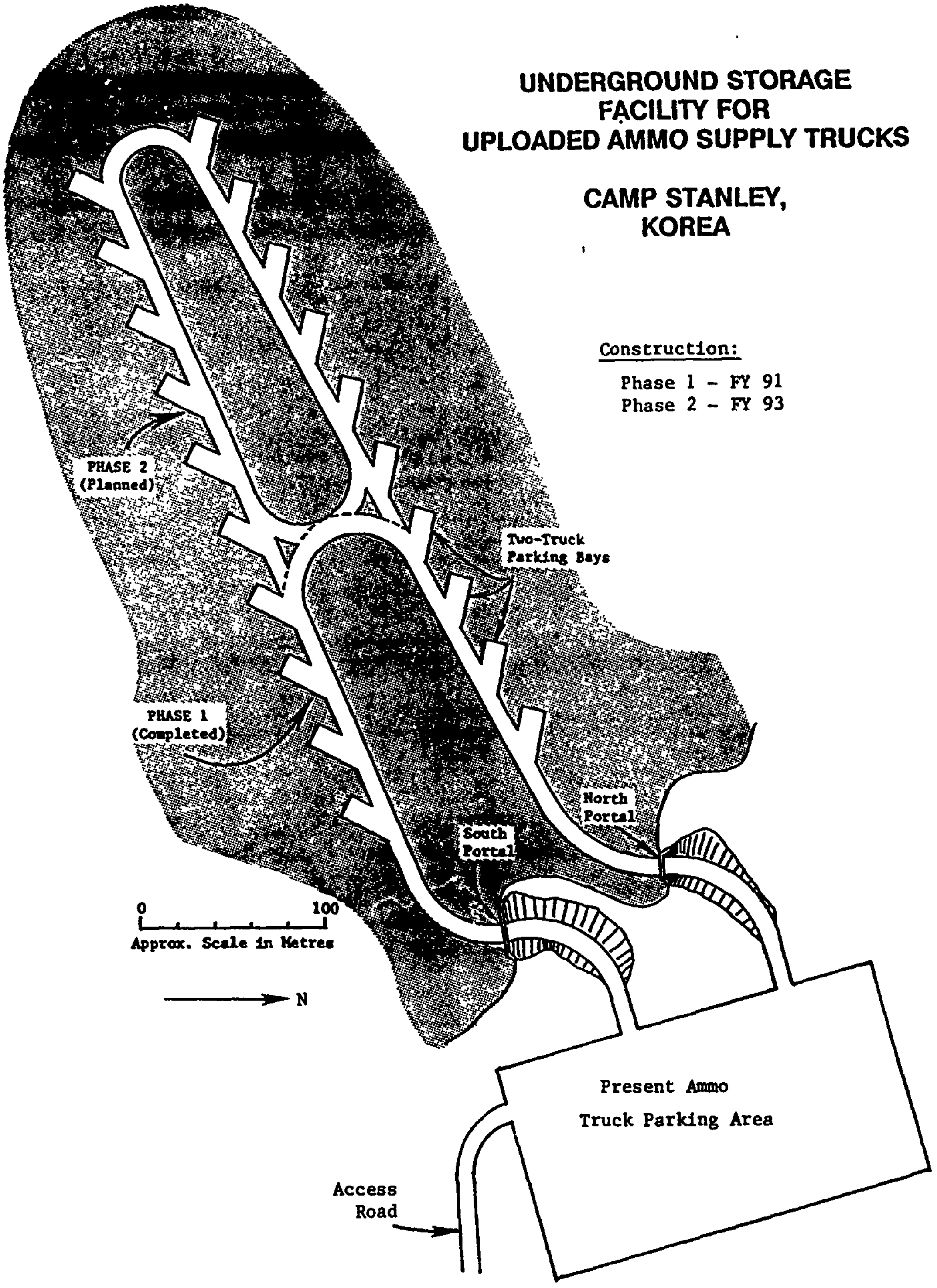

Figure 1. Layout (plan view) for Camp Stanley Underground Ammunition Storage Facility

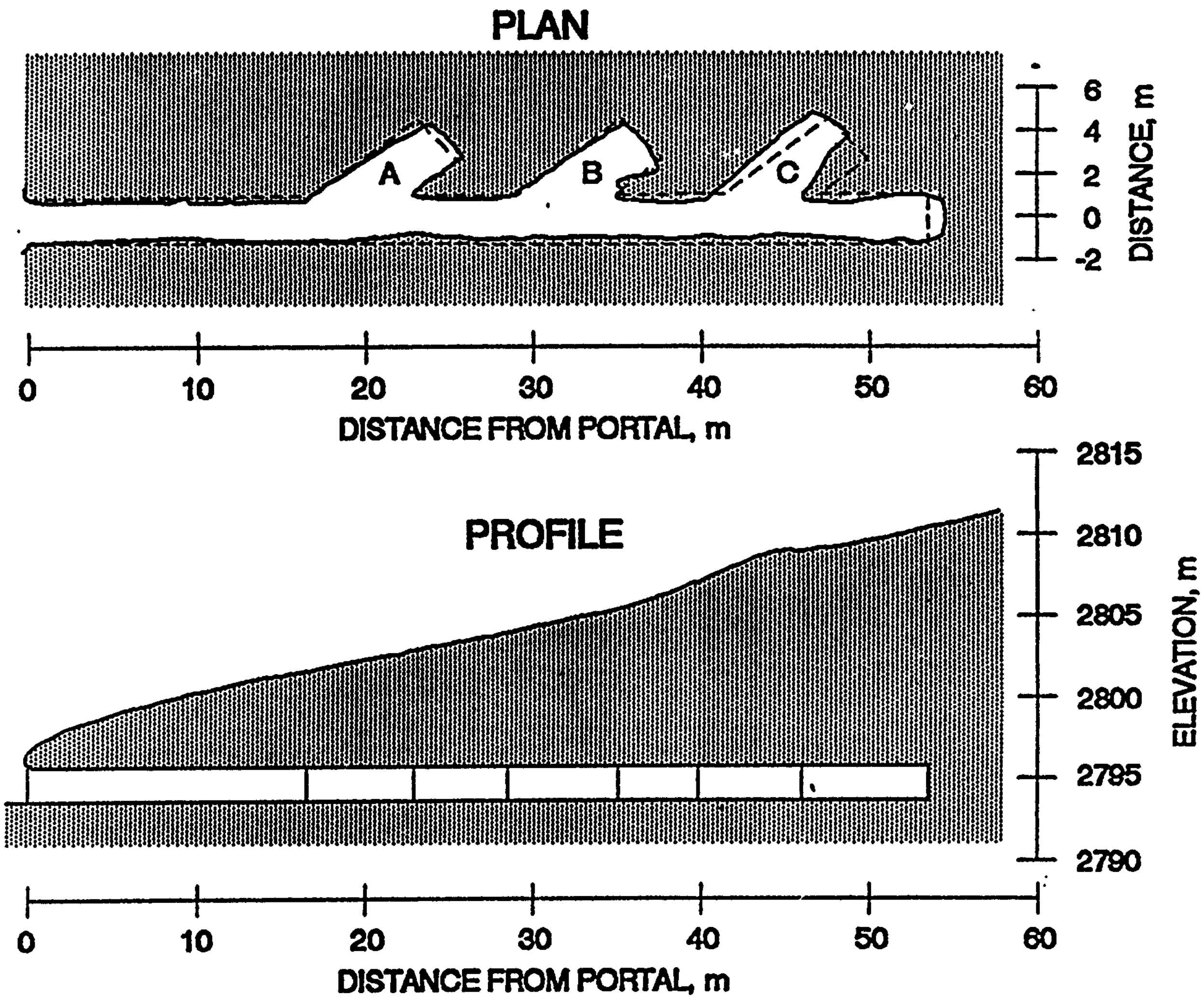

Figure 2. Longitudinal tunnel cross-section (plan and profile) for 1/3-Scale Camp Stanley Validation Test. Letters identify donor (B) and acceptor adits (A and C).

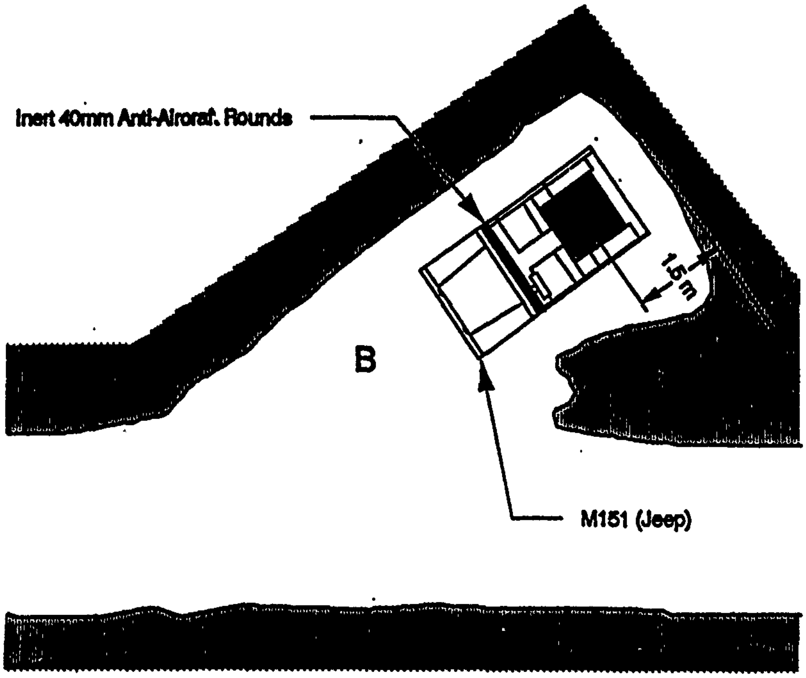

Figure 3. Location of 336-kg Comp B donor charge for Test 3, 1/3-Scale Camp Stanley Validation Test. Explosives were placed upon a surplus M151 vehicle located in adit B.

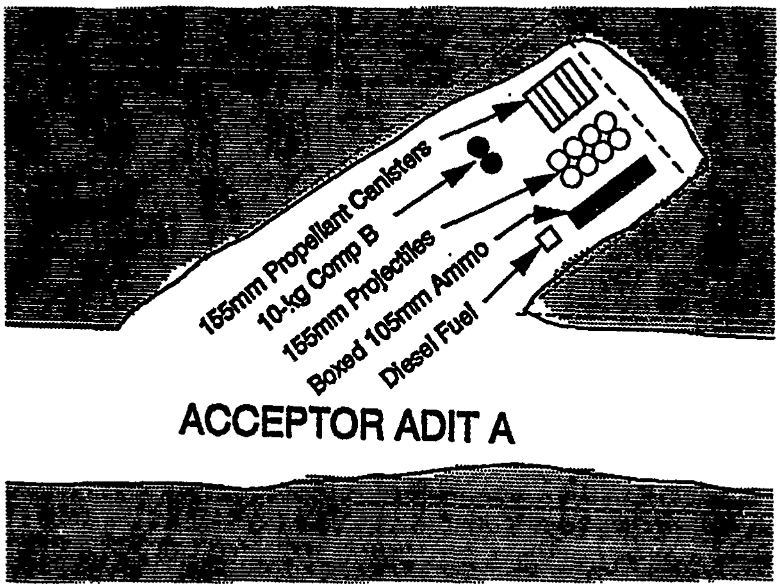

Figure 4. Placement of acceptor munitions within Acceptor Adit A for Test 3.

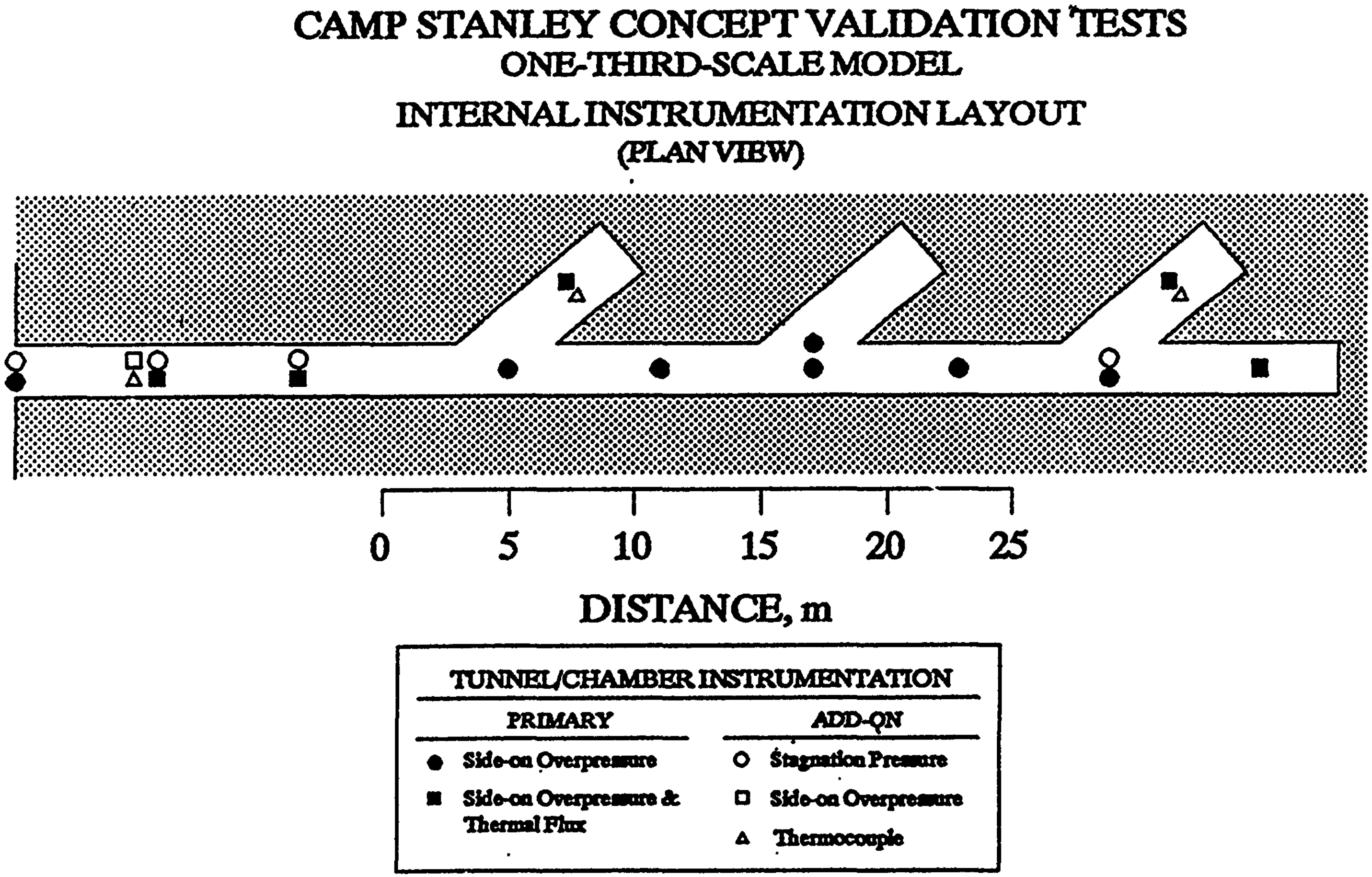

Figure 5. Interior transducer locations for 1/3-Scale Camp Stanley Underground Munitions Storage Concept Validation Test.

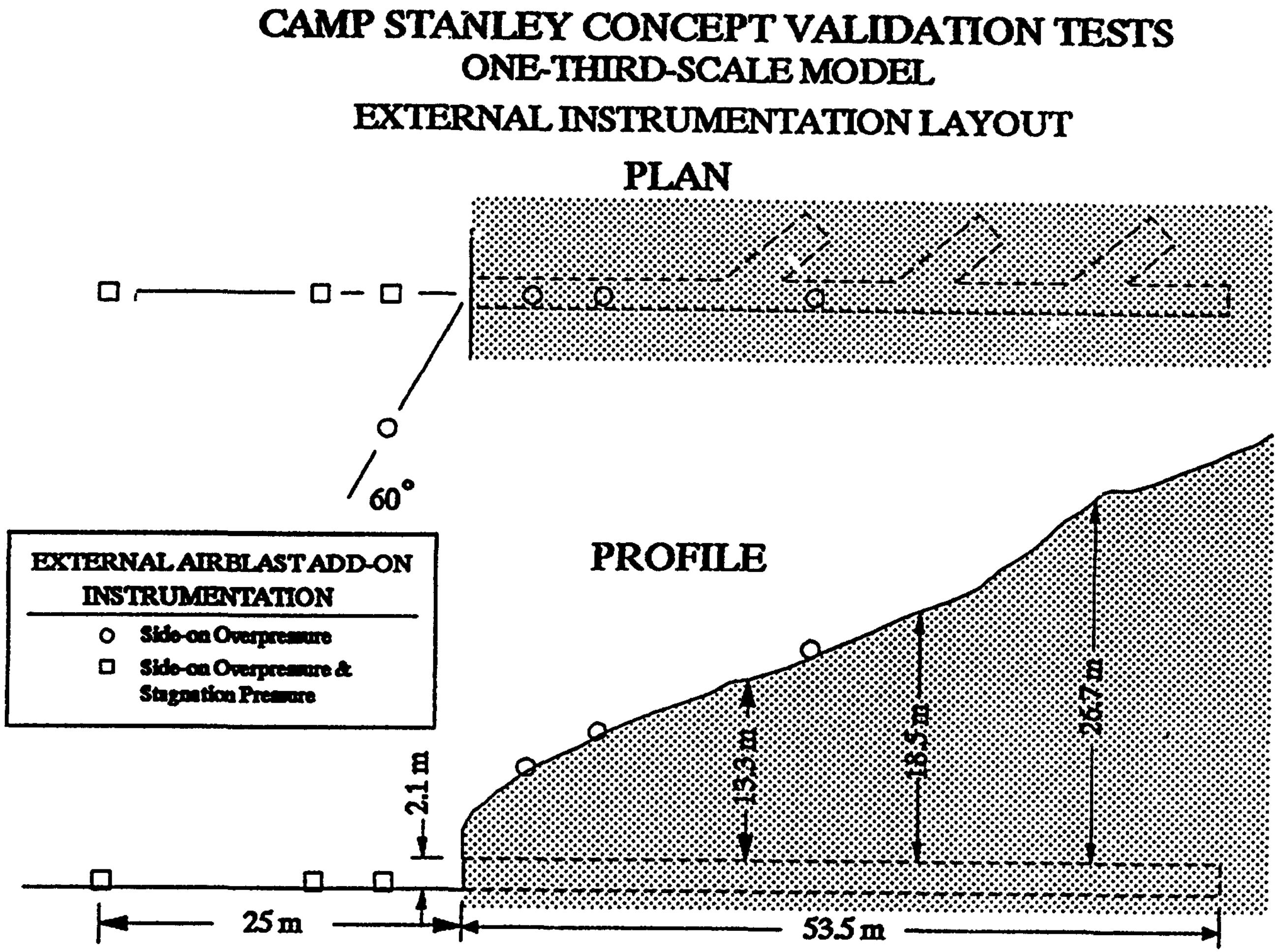

Figure 6. External airblast gage locations, 1/3-Scale Camp Stanley Underground Munitions Storage Concept Validation Test.

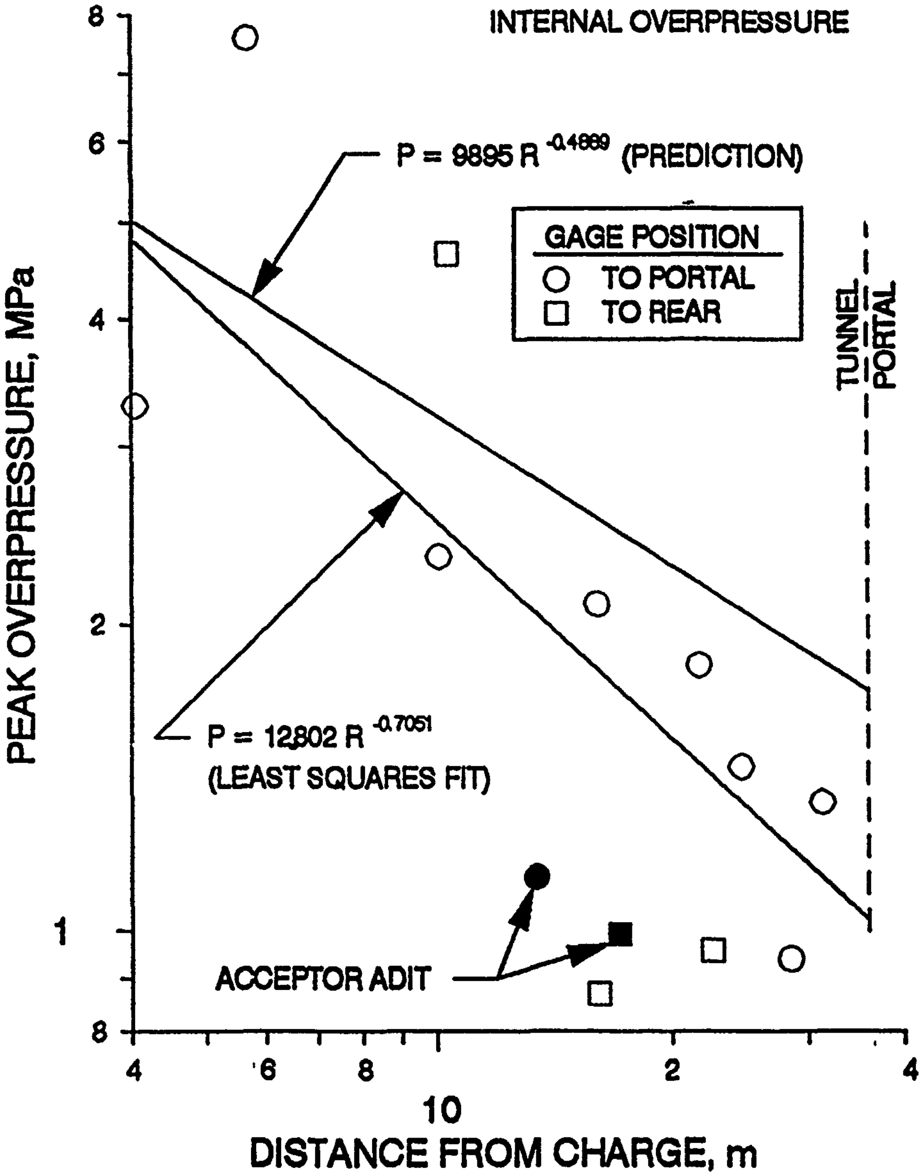

Figure 7. Comparison of peak overpressure measurements, 1/3-Scale Camp Stanley Munitions Storage Concept Validation Test. Gage positions "to rear" are between donor adit and rear of tunnel. Those "to portal" lie between donor adit and portal. Least squares fit includes only "to portal" data.

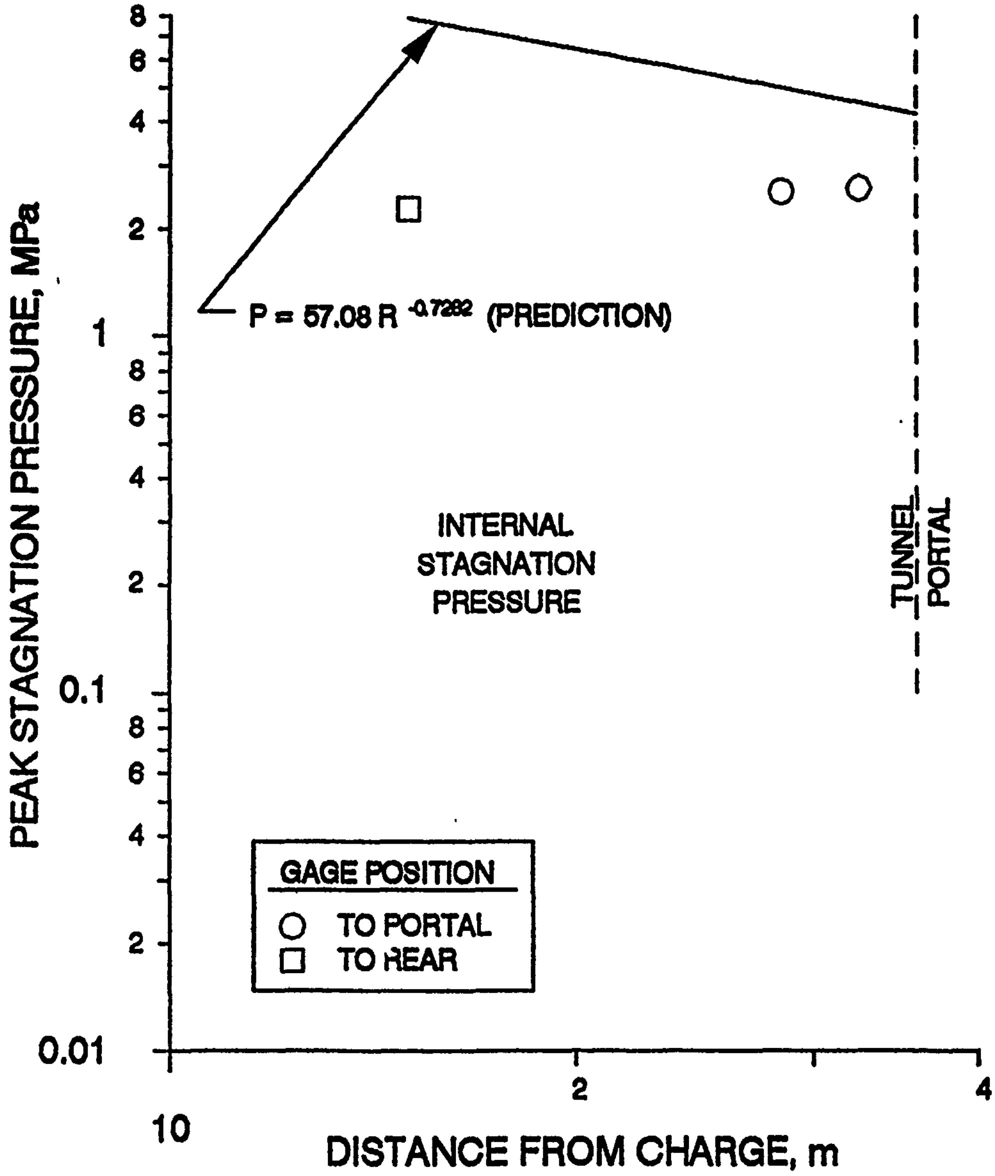

Figure 8. Peak stagnation pressure versus distance from initiation point of donor charge, 1/3-Scale Camp Stanley Munitions Storage Concept Validation Test.

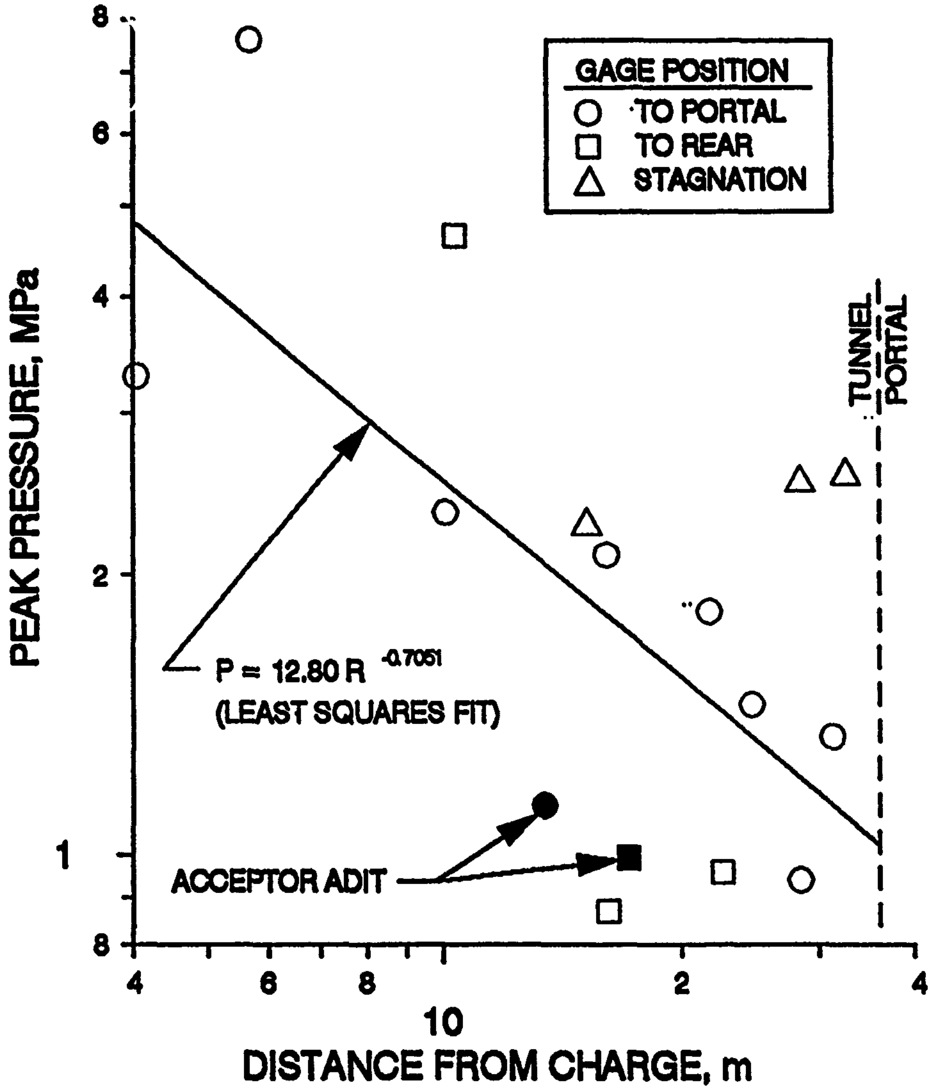

Figure 9. Comparison of internal airblast pressures (side-on and stagnation), 1/3-Scale Camp Stanley Munitions Storage Concept Validation Test. Gage positions "to rear" are between donor and rear of tunnel. The "to portal" positions lie between the donor and the portal. Least squares fit includes only "to portal" data.

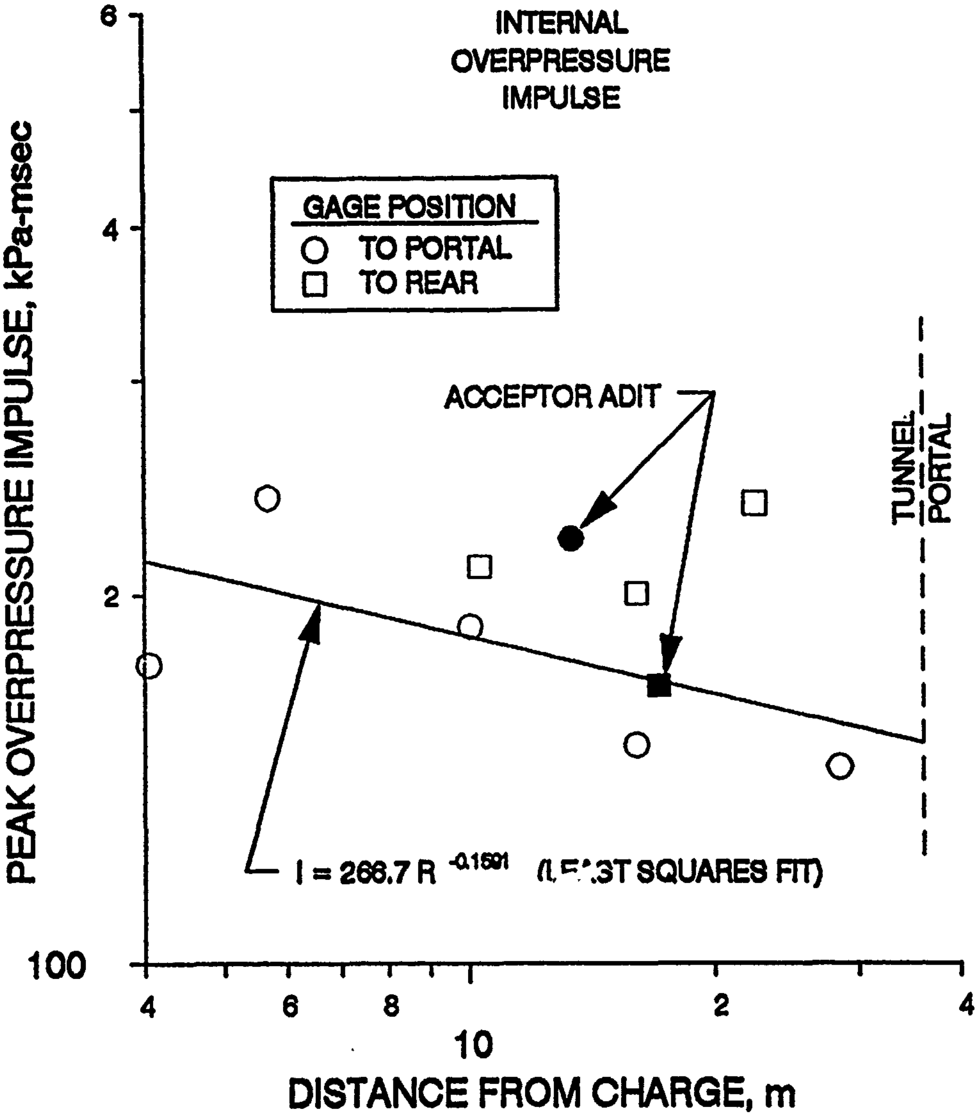

Figure 10. Comparison of peak overpressure impulse, 1/3-Scale Camp Stanley Munitions Storage Concept Validation Test. Gage positions "to rear" are between donor and rear of tunnel. The "to portal" positions lie between the donor and the portal. Least squares fit includes only "to portal" data.

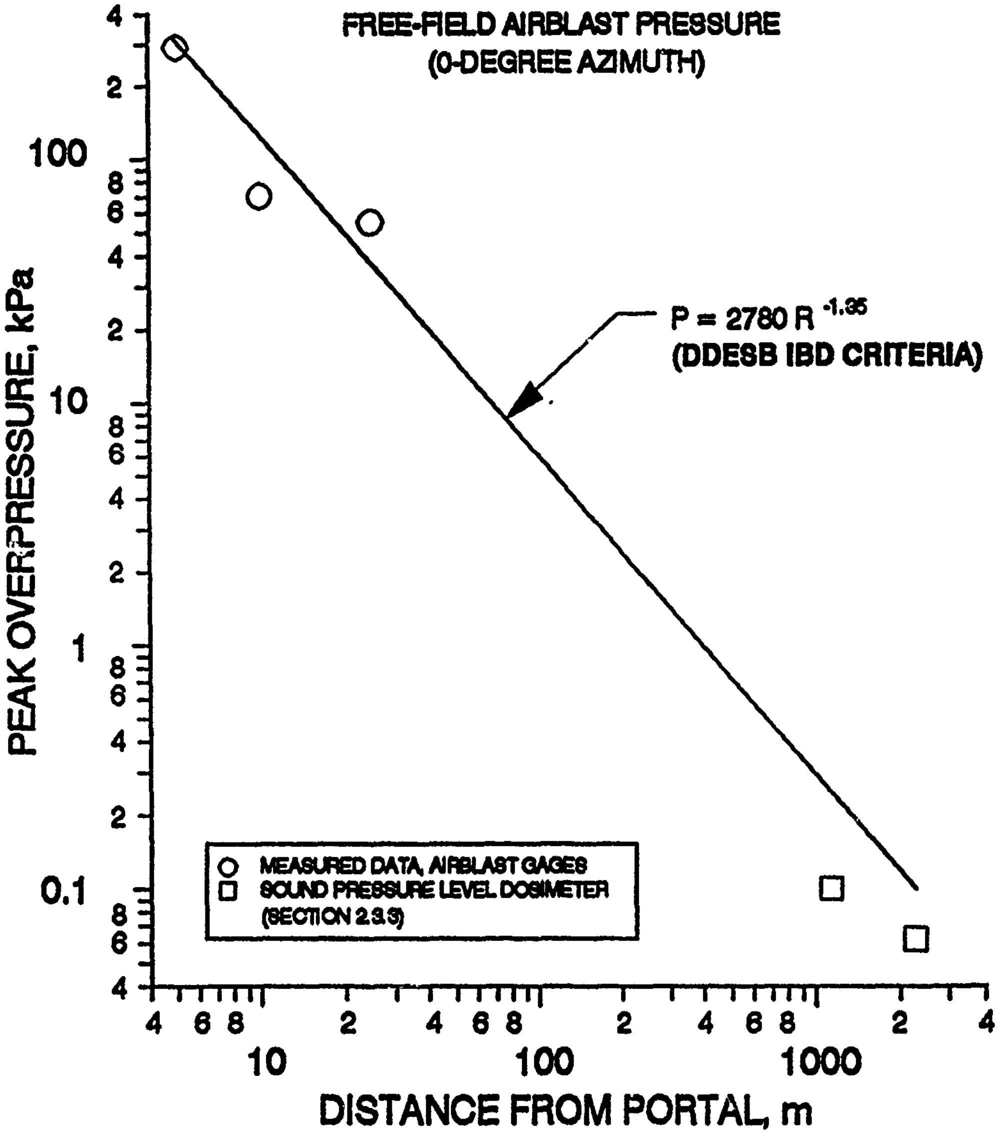

Figure 11. Comparison of predicted and measured free-field airblast data, 0-degree azimuth, 1/3-Scale Camp Stanley Munitions Storage Concept Validation Test.

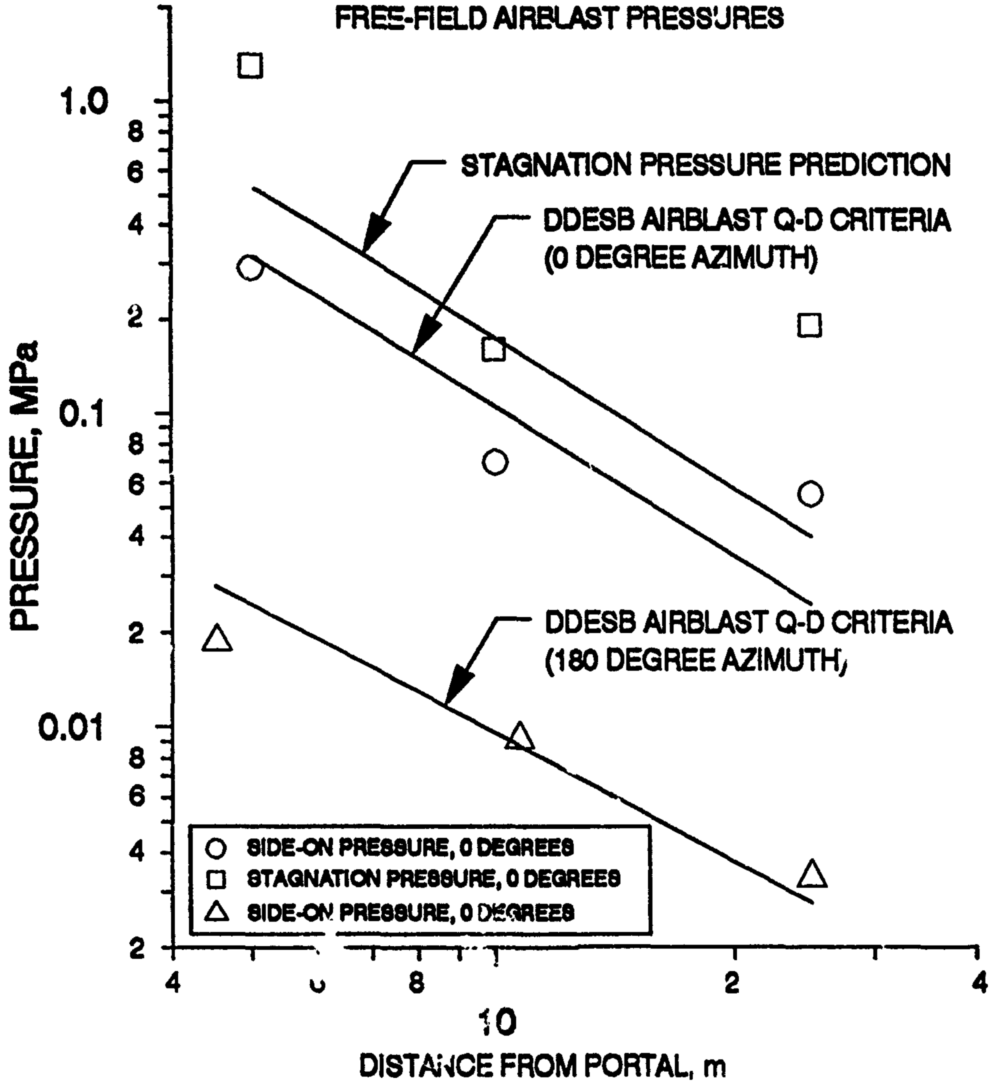

Figure 12. Comparison of predicted and measured free-field airblast pressures (side-on and stagnation), 1/3-Scale Camp Stanley Munitions Storage Concept Validation Test.

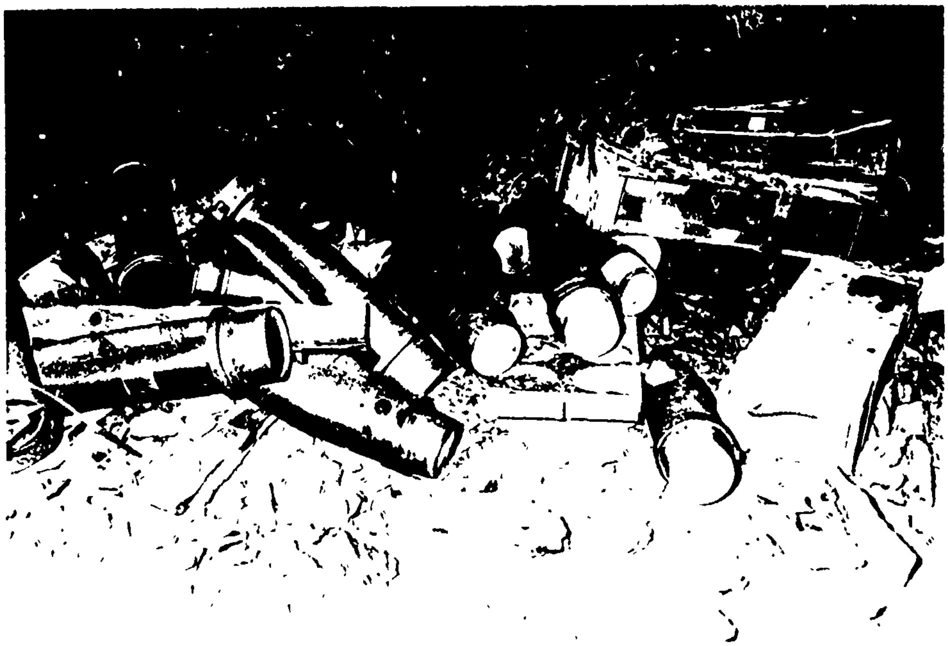

Figure 13. Post test positions of acceptor munitions in Acceptor Adit A.

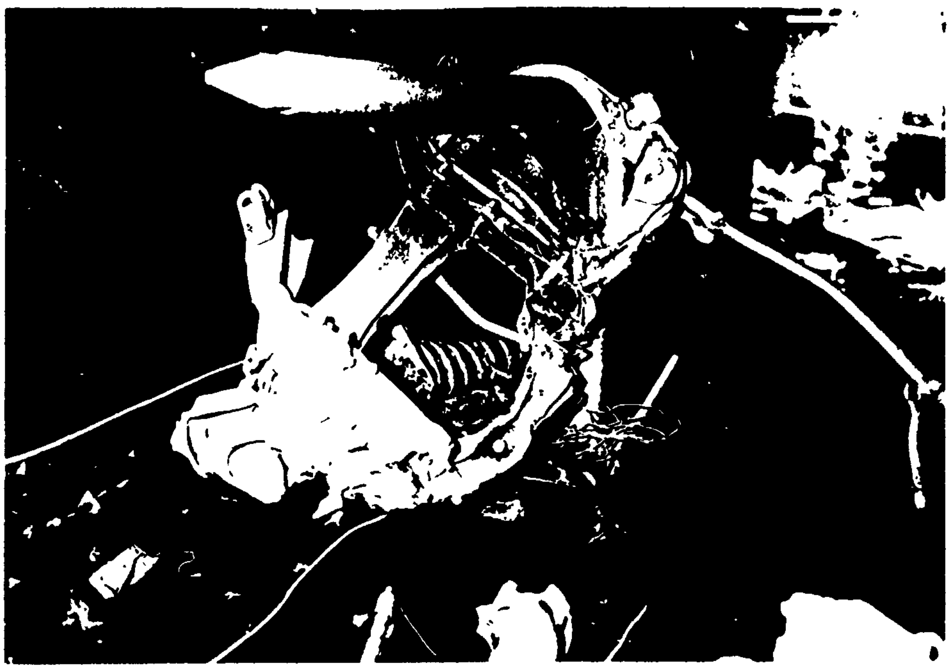

Figure 14. Post test tunnel debris trapped by stagnation pressure mount.

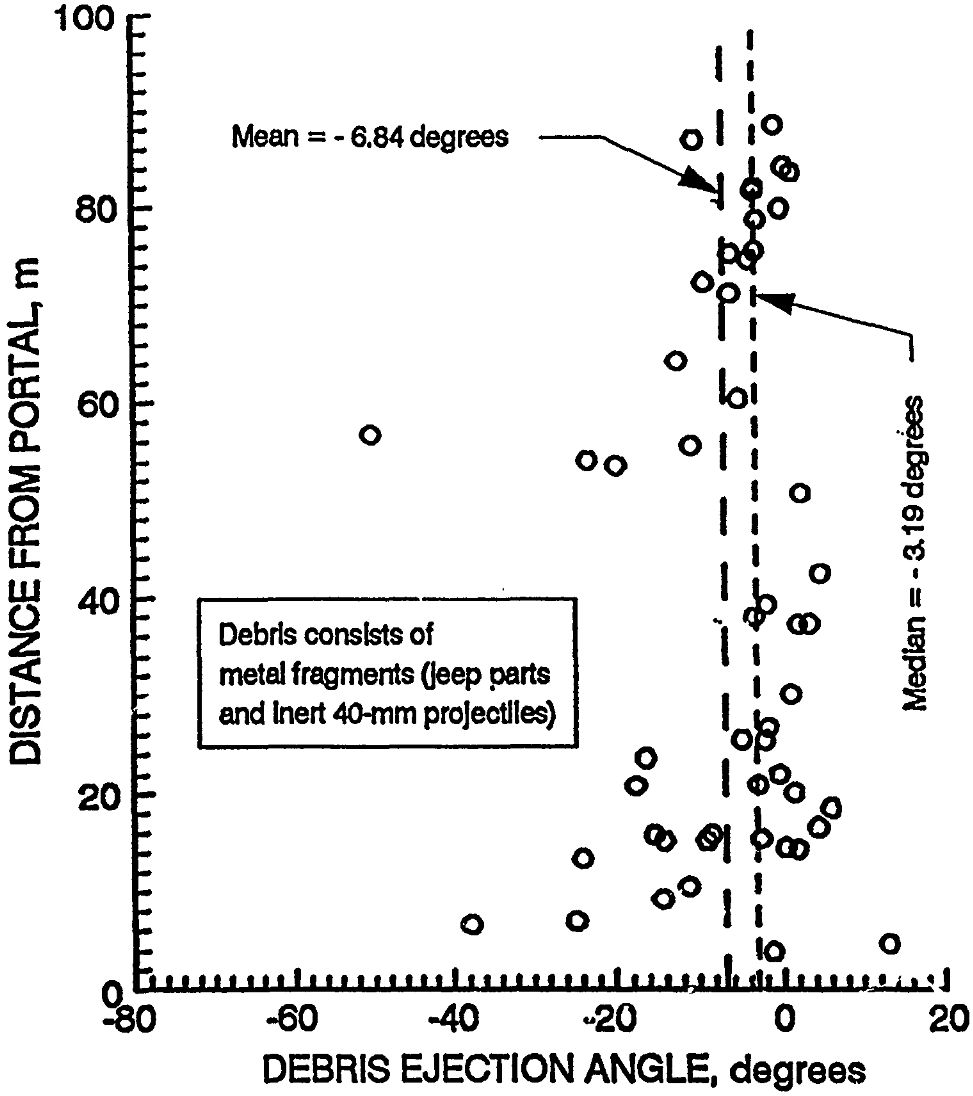

Figure 15. Debris distance from the portal versus angular position (relative to the extended access tunnel centerline).

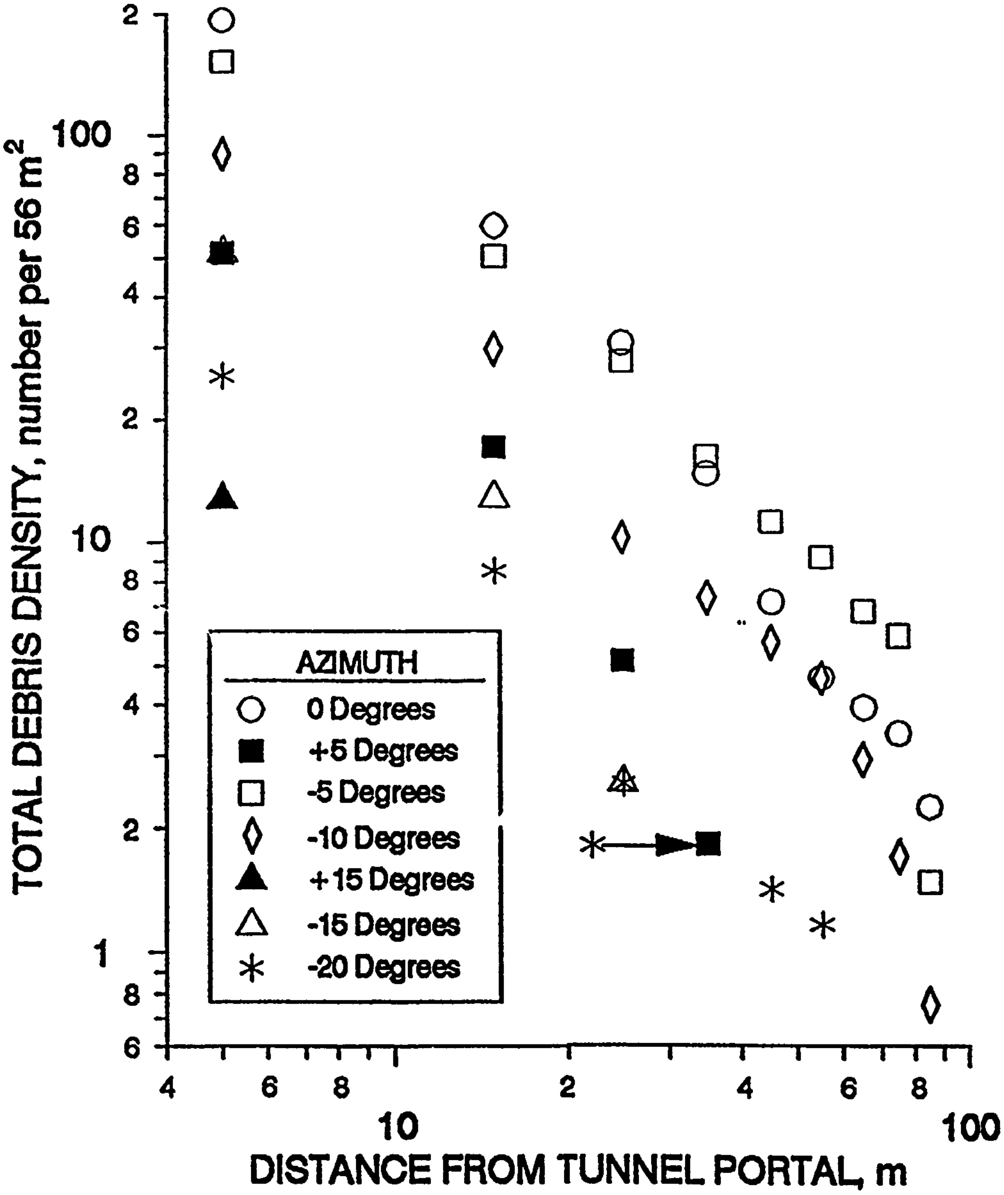

Figure 16. Total debris density versus distance from the portal to the center of the collection zone. Total density is defined as the number of debris fragments found within the collection zone plus the number of pieces which are collected in the same sector beyond the collection zone.

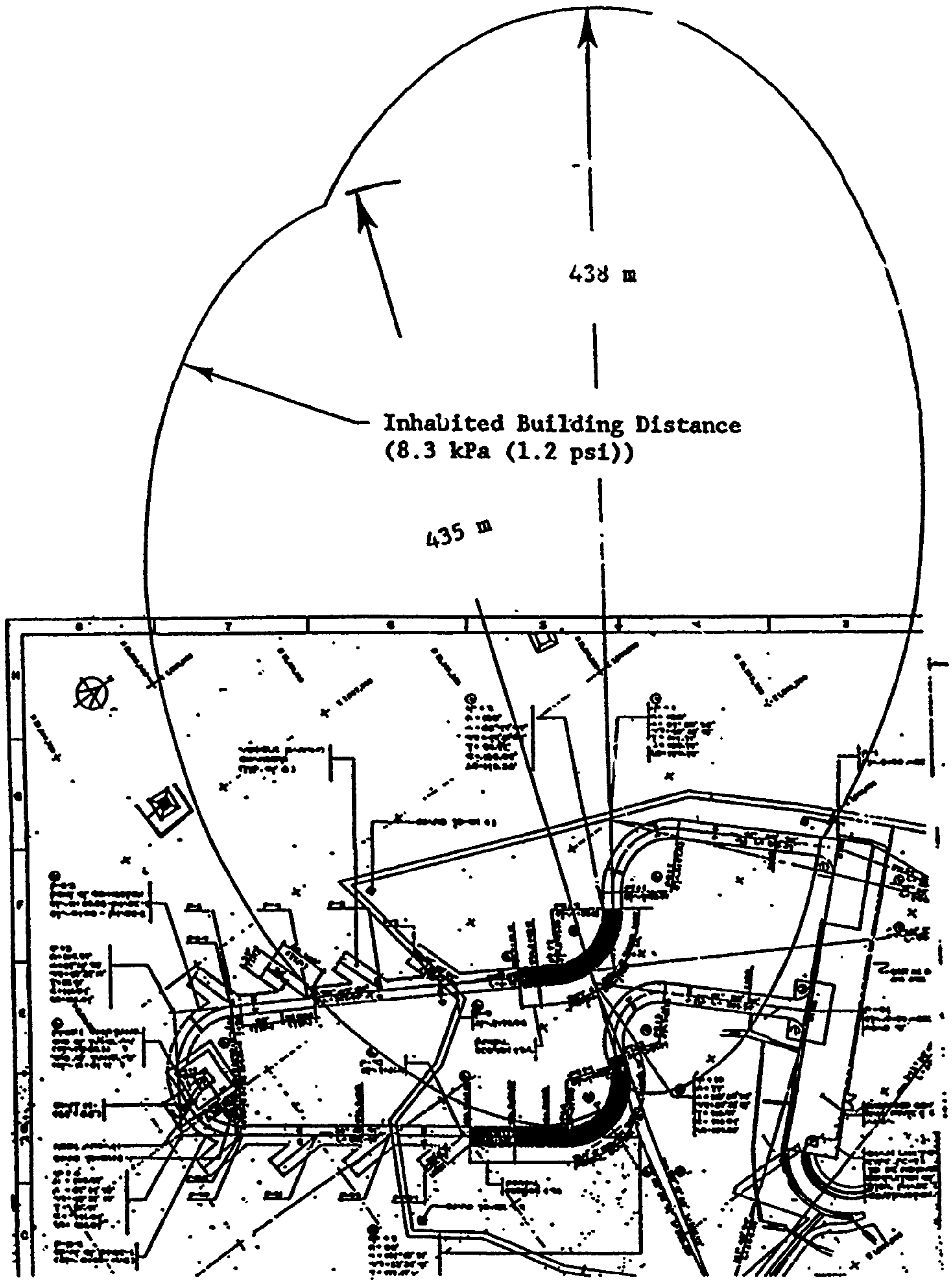

Figure 17. Camp Stanley Underground Munitions Storage Facility airblast Inhabited Building Distances as specified by Standards (DOD 6055.9-STD). Worst case obtained by assuming superposition of airblast shock fronts from accidental detonations of 9080-kg NEQ (20,000-lb NEW) in right and left rear parking adits.

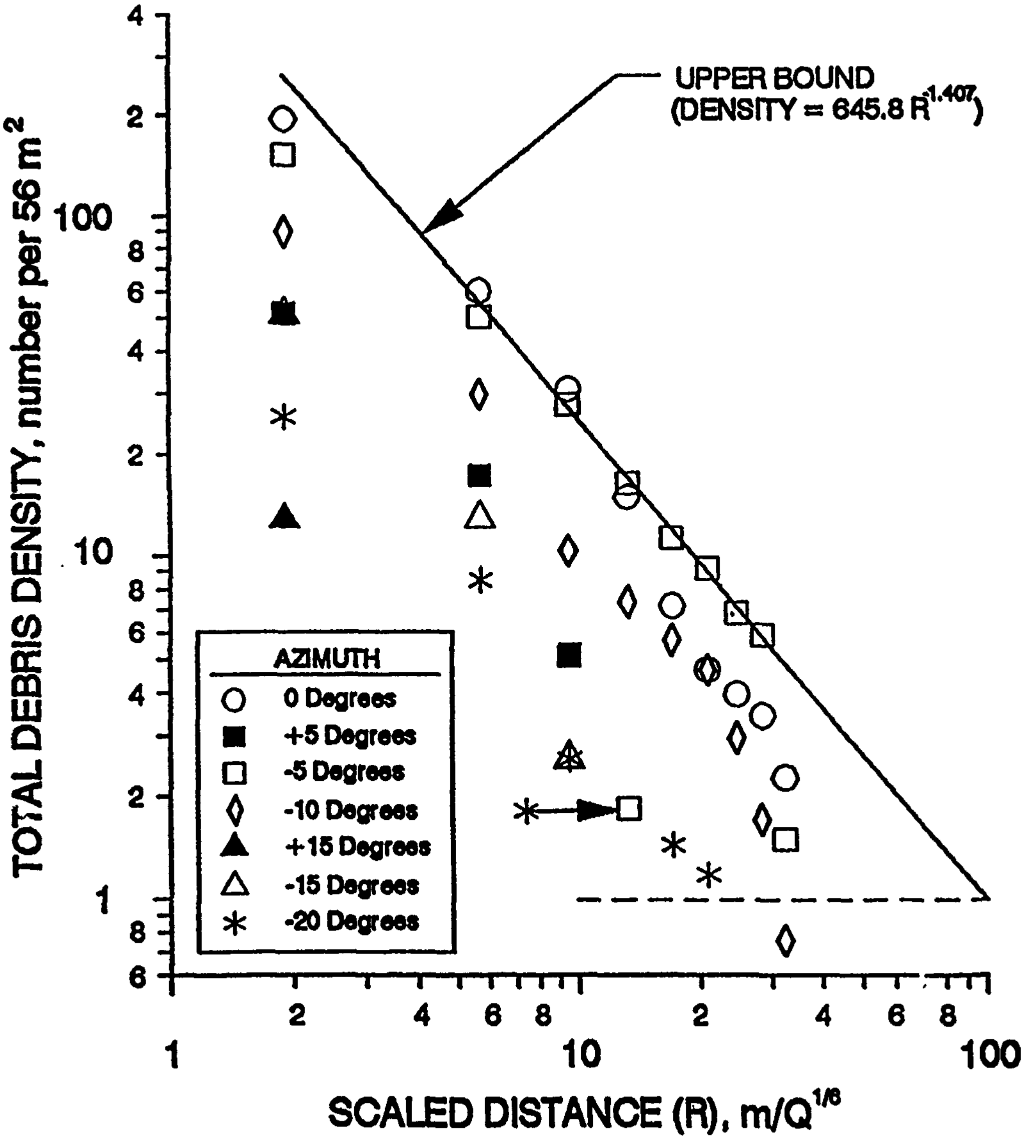

Figure 18. Total external debris density versus scaled distance from the portal, from the 1/3-Scale Camp Stanley Validation Test. Total density is defined as the number of fragments found within the collection zone plus the number of pieces which are collected in the same sector beyond the collection zone.

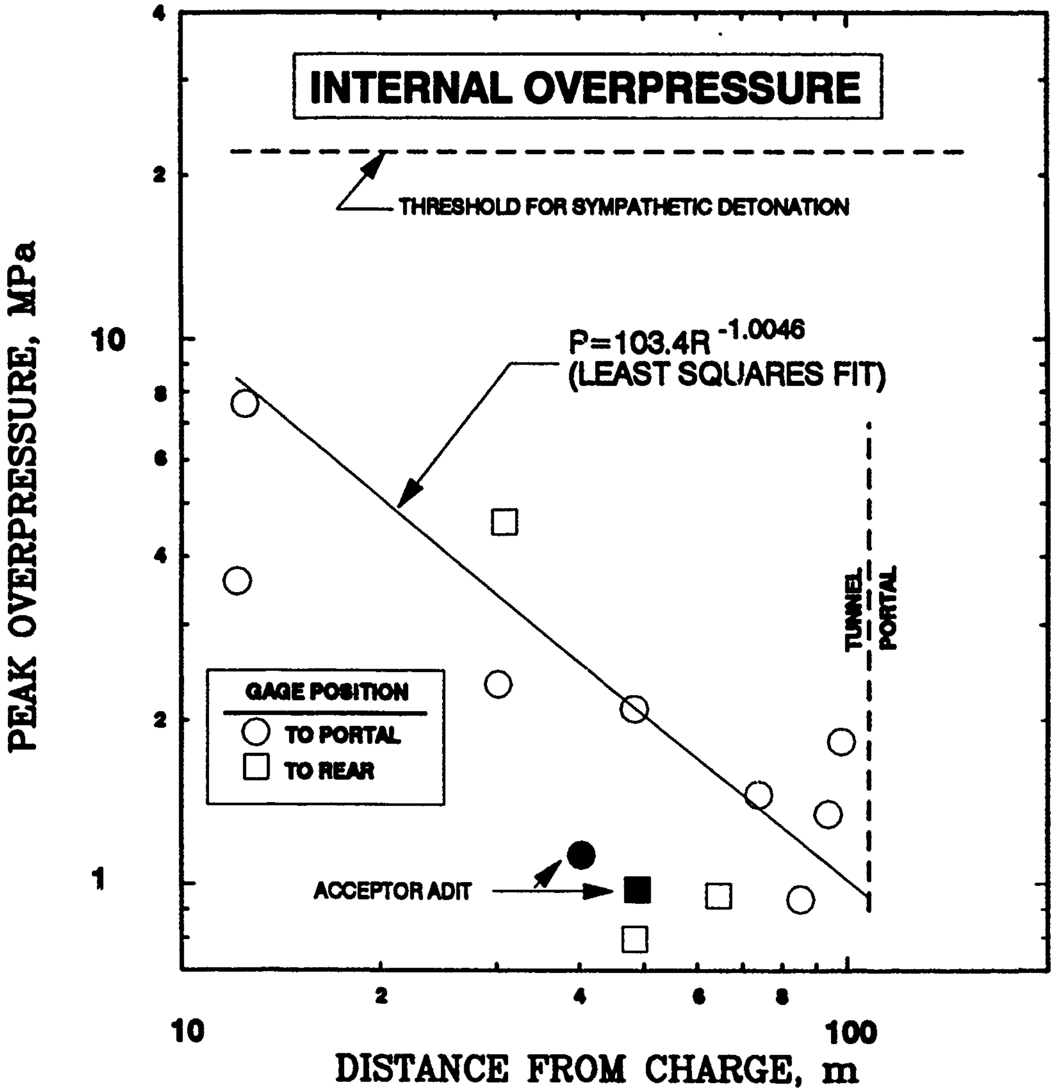

Figure 19. Comparison of peak internal overpressure and threshold for sympathetic detonation defined as the pressure and impulse from a 227-kg (500-lb) surface detonation at a range of 1 metres. CONWEP calculated values of overpressure and impulse are 22.15 MPa and 3189 kPa-msec, respectively.

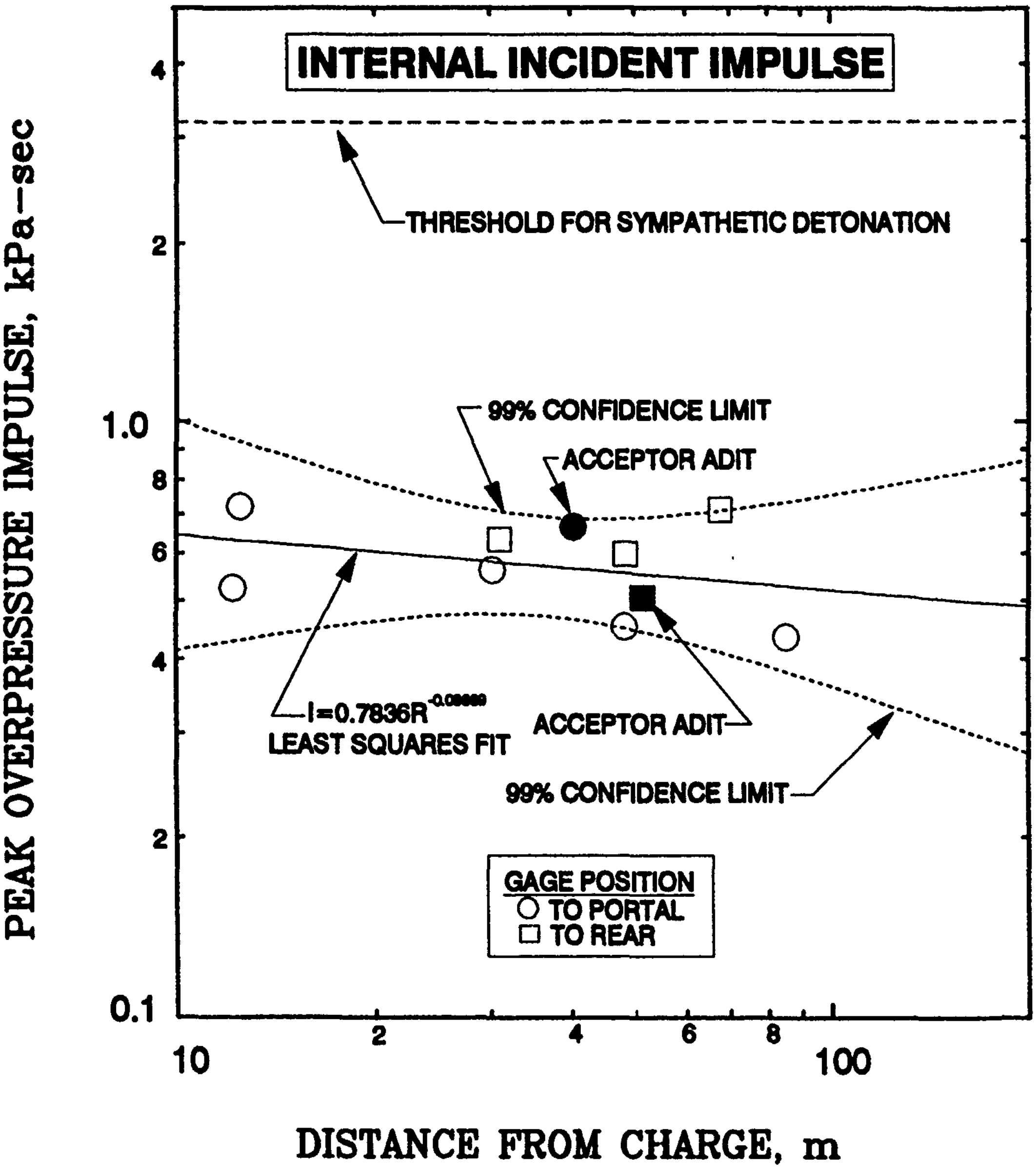

Figure 20. Comparison of peak internal incident impulse and threshold for sympathetic detonation defined as the pressure and impulse from a 227-kg (500-lb) surface detonation at a range of 1 metres. CONWEP calculated values of overpressure and impulse are 22.15 MPa and 3189 kPa-msec, respectively.

Hydrocode Calculations for Simulation of 1/3-Scale Munitions Storage Facility Tests

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1. Abstract/Introduction

In July and August, 1991, the Army Waterways Experiment Station, with partial support by the KLOTZ Club, conducted a series of underground explosive tests at a location near Denver, Colorado. The primary purpose of the tests was to determine if an accidental explosion of ammunition located in one storage bay would cause the sympathetic detonation of munitions in an adjacent bay. The tunnel and bays constructed for these tests represented, at 1/3 scale, a section of the underground munitions storage facility planned for construction at the U.S. Army's Camp Stanley, in South Korea.

The Camp Stanley facility is designed to serve three purposes: (1) to protect the post and surrounding villages from the effects of an accidental explosion; (2) to protect the munitions from sabotage or enemy attack (the camp is within artillery range of North Korea); and (3) to allow rapid deployment of the ammunition in the event of a surprise attack. To support the last requirement, the ammunition is to be stored loaded on trucks that can be manned and driven out of the facility within a few minutes after a war alert.

In Colorado, three bays were constructed, and all three were loaded with explosives. The center bay contained a "donor" test charge. For the largest test, this charge consisted of 336 kg of Composition B loaded on a jeep. Sections of steel rods or inert ordnance rounds, scaled approximately to 1/3 the size of 155-mm projectiles, were placed in front of the donor charge to simulate unexploded ammunition. The two "acceptor" bays contained live 155-mm and smaller ammunition.

S-Cubed's contribution was to provide accurate pre- and post-test airblast calculations for this 336-kg test. The calculations were run using SHARC, S-Cubed's state-of-the-art, second-order-accurate hydrodynamic material-response code. Pre-test calculations, designed according to pre-test plans with measured cross-sectional areas, produced airblast predictions which were somewhat higher than the test data. On re-running the calculations using dimensions for the facility as actually measured prior to the test, significantly improved correspondence of calculated and experimental results was obtained. Earlier tests had modified the interior dimensions somewhat by breaking

pieces of rock from the floor, walls, and overhead. The results point out the importance of obtaining accurate internal volume information before attempting to predict the airblast effects, both internal and external, from an explosion within a confined facility.

2. The Calculational Model

2.1 Charge Detonation Calculations

The calculations for charge detonation and interior airblast propagation were performed with the SHARC code in two dimensions in a Cartesian coordinate system. Figure 1 is a plan view of the tunnel system as modeled for the hydrocode. At the time the pre-test calculation was set up, cross-sectional area data was available at several locations in the tunnel. This data was used, along with a pre-construction diagram, to define the interior. The calculational model was developed so that the cross-sectional areas of the tunnel were conserved in two dimensions. Based on a nominal tunnel height of 2.1 m for the unmodeled third dimension, widths for the different tunnel sections were calculated. A linear interpolation was used between the sections where area data was available. The length of all tunnel sections was modeled as planned.

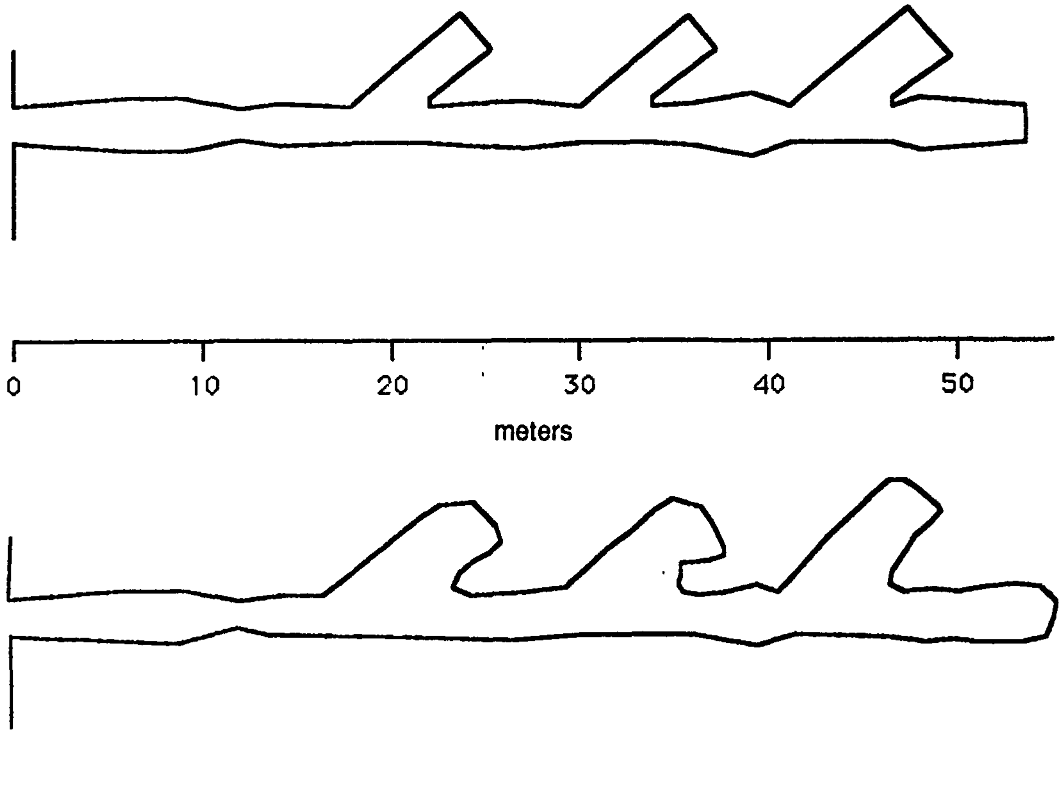

Figure 1. Plan view of tunnel configurations as modeled for the calculations. The upper figure is the pre-test configuration; lower figure is post-test.

For the post-test calculation, a slightly different plan-view configuration was used. This was based on more complete, as-tested information available at the time the second calculation was run. The second configuration included a wider donor bay, with part of the divider wall broken away, and a longer main tunnel. The post-test configuration is also shown in Figure 1. The pre-test tunnel volume was modeled as 371 m^3, whereas the volume for the post-test calculation was 429 m^3. The difference is approximately 15%.

The dimensions of the charge were determined from the loading density of the explosive. In the test, flakes of Comp-B were placed in a rectangular container and compressed by a weight placed on top of the charge. The resulting loading density was approximately 0.85 grams/cc. From this, the charge dimension for the calculation was determined to be 43.4 cm square. The detonation point was placed at the center of the charge.

In the test, the charge was placed in the back of a jeep, which was parked along the center line of the donor bay. In a two-dimensional model, only material which surrounds the charge can be included. For this reason, the weighted cover of the explosive box was not modeled. The jeep, however, was modeled using massive, drag-sensitive, flow-interactive particles. Twelve of these particles were placed around the charge to represent the jeep. Additional particles were included to represent inert 40-mm anti-aircraft rounds. Figure 2 shows the configuration of the charge and the particles and stations in the donor bay as they were modeled for the calculation.

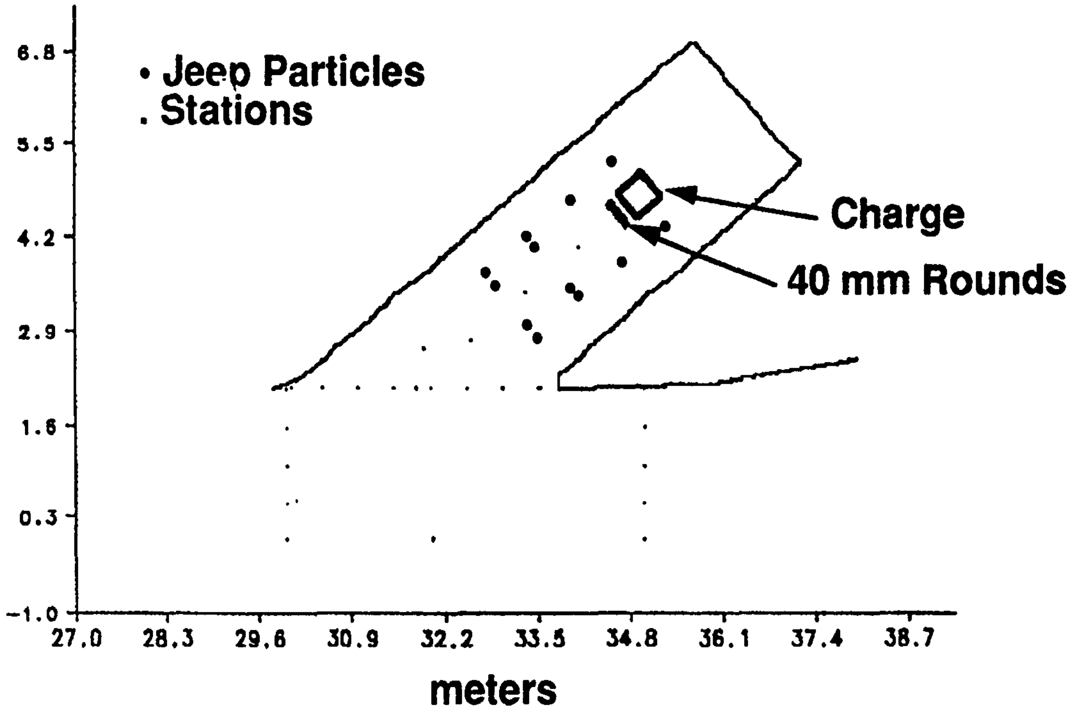

Figure 2. Configuration of charge, massive particles, and stations in donor bay as modeled for the calculation.

Stations were placed at test gage locations and at several other locations within the tunnel system and outside of the tunnel entrance. Stations were also placed in both the donor and acceptor bays, throughout the main tunnel, and on radials outside the tunnel entrance at 15-degree intervals. The dots in Figure 2 represent a number of these stations.

The granite walls within the tunnel system were modeled in the calculation with "material islands". SHARC is a hydrocode and hence does not include material stresses. The material island capability was developed to model the breakdown of material when subjected to high pressures. A material island zone is treated as a non-responding, perfectly-reflecting zone until the pressure in an adjacent zone exceeds a pre-set "yield stress." When this occurs, the zone is converted to another material— in this case, granite— and the hydrodynamic compression and transport of material is subsequently allowed in that zone. It was expected that pressures on the walls of the donor bay near the charge would exceed the yield stress of granite. Results of the calculation will show that this was the case. For all calculations, the yield stress of the granite was set to 400 MPa. Reconversion of the granite cells to islands after pressure levels have declined has not been found to be necessary.

A total of 68,500 zones were used in the computational mesh for the pre-test detonation calculation; 108,500 zones were used for the post-test version. In both cases, zone dimensions were 3 x 3 cm. Ambient air for the calculation was provided at sea-level conditions for the pre-test calculation. For the post-test case, ambient conditions were modified to those more representative of the test location, at an altitude of approximately 2.8 km above sea level.

The detonation calculation was run to a time of 1.4 msec (pre-test case) or 1.2 msec (post-test case) after charge detonation. At this time, the initial expanding blast wave has filled the entire donor bay and has moved into the main tunnel region. Figure 3 is an air density contour plot from the pre-test calculation at 1.4 msec showing the location of the shock front. The square regions at the corners and sides of the bay are regions where the material islands have been activated, allowing some expansion of air into these zones.

2.2 Interior Blast Propagation Calculations.

At the end of the computational time for the detonation calculations, conditions were mapped into a larger mesh which included the entire interior of the tunnel complex, plus a small portion of the region outside the tunnel portal. This change allowed the use of 10-cm zones, which provided for computational efficiency. The fine detail needed for detonation of the explosive was no longer necessary in this blast propagation phase. The mesh contained 564 zones in the longitudinal direction and 138 zones in the lateral direction, for a total of 77,832 computational zones. The post-test calculation required a

few more zones in the longitudinal direction, 578, because the post-test tunnel was slightly longer.

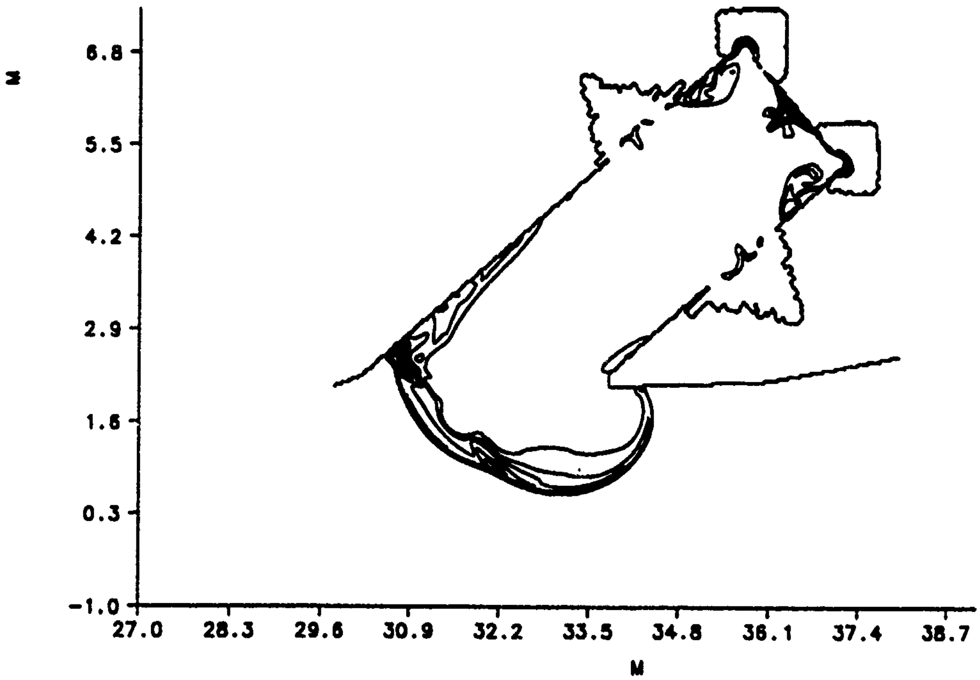

Figure 3. Air density contour plot from pre-test calculation at 1.4 msec, showing location of the shock front and material island interactions.

The material island model was also used in this phase of the calculations, but because the maximum pressure in the mesh was well below the yield stress of granite, none of the zones were converted to hydrodynamic granite during this phase . Stations were included at the same locations as those in the detonation calculation. In addition, in the tunnel near the entrance, a group of stations was spaced across the width of the tunnel to record detailed waveforms at this location. These waveforms were used to drive the exterior airblast calculation. The pre-test calculation was run to a time of 150 msec after detonation, in order to obtain sufficient data to drive the exterior calculation. The shock front was allowed to exit the mesh at the boundaries outside of the tunnel. The post-test version was run only to 30 msec.

2.3 Exterior Blast Propagation Calculations.

Only the pre-test configuration was used to drive an exterior calculation. This exterior calculation was also run in two stages. The first started at 14 msec after detonation and was run to 120 msec. The second calculation ran from 120 msec to 400 msec. The two stages were used so that good resolution of results would be provided in both the portal and far field regions.

For the exterior calculations, a cylindrically-symmetric configuration like that shown in Figure 4 was used. The axis of symmetry was the zero-degree line along the center of the tunnel floor. The radius of the tunnel entrance was adjusted so that the area of the half-cylindrical tunnel matched that of the rectangular tunnel from the earlier Cartesian calculations. This configuration has been found to be more realistic than a Cartesian mesh when calculating expansion into a surface-limited open space.

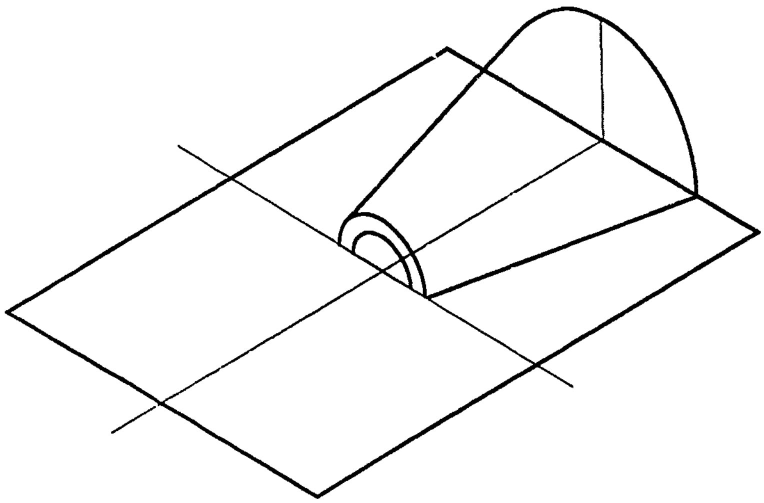

Figure 4. Configuration for cylindrically symmetric calculations performed to model external expansion of the blast wave from the tunnel portal.

The first external stage contained a total of 79,200 zones, 160 in the radial direction and 220 in the axial direction, to define the computational domain. The mesh encompassed a region from 0 to 52 meters above the reflecting plane and from 5 meters inside the tunnel to 70 meters outside the portal. The initial mesh was filled with air at ambient sea-level conditions, as for the interior calculations. The remote boundaries were designated as transmissive to allow flow to exit the mesh. The boundary 5 meters inside the portal was modified to allow the continuous feed-in of flow conditions from the station records of the interior calculation. The feed-in routine places internal energy, density, velocity, and material density information in the boundary zones at every calculated cycle, using a linear interpolation in space and time of the data from the feed-in stations. Both horizontal and vertical components of velocity are used to preserve the flow component across the width of the tunnel. This same boundary outside the tunnel was designated as transmissive.

Smoke trails were used in the experiment to obtain a representation of the flow field in the region just outside the portal. These trails were modeled in the calculation with massless tracer particles. These massless particles, unlike the massive particles used to model debris, move with the flow but do not interact with it. Vertical lines of particles were placed at 7.6, 12.5, 17.4, 22.3, and 27.4 meters (25, 41, 57, 73, and 90 feet) from the

portal, extending to a height of 14 meters above the plane of symmetry. An additional line of particles was placed starting at a height of 9.8 meters (32 feet) above the tunnel entrance and extending a distance of 20 meters, rising at an angle of 4° from its initial point. The tracer particle/smoke trail layout is shown in Figure 5. Stations were placed in the mesh at the entrance and inside the tunnel, at test gage locations, and on 15-degree radials outside the tunnel entrance.

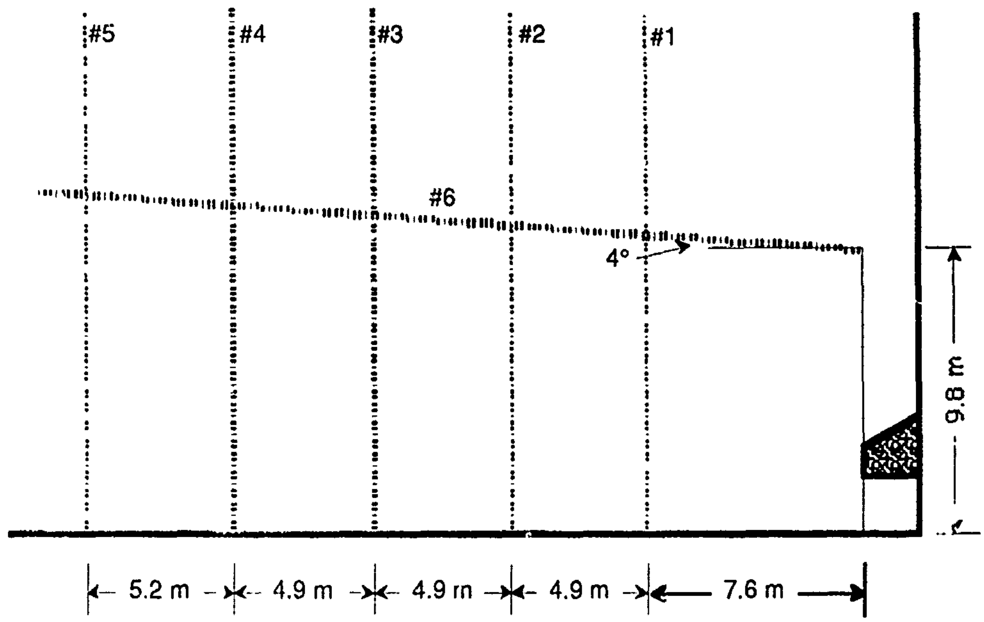

Figure 5. Massless tracer particle layout configured to correspond to experimental smoke trails.

At a time of 120 ms after detonation, the conditions in the mesh were mapped into the larger mesh of the second exterior phase to allow calculation of the airblast to low overpressure levels (50 mbar). The shock front at 120 ms is about 50 meters from the tunnel entrance on the zero degree radial. The mesh for the second phase extended the top and right boundaries to 150 and 121 m, respectively. A constant subgrid of zones with a zone size of 10 cm was located near the tunnel entrance, with zones above and to the right of the subgrid expanding with distance at a constant ratio of about 1.02 to a maximum size of 50 cm at the mesh boundaries.

The same boundary feed-in conditions inside the portal used for the earlier phase were used for this part of the calculation. Beyond the last time of the Cartesian calculation (150 ms), constant values were fed into the mesh at this boundary.

The second phase was run to a time of 400 ms. By this time, the shock front had exited the calculational mesh. The peak overpressure at the shock front along the zero-degree

radial was approximately 64 mbars at a radial distance of 140 meters from the tunnel portal.

3. Results from the Calculations

3.1 Pre-test Calculations

The pre-test calculations were conducted as described in the previous section. Two contour plots are shown to illustrate the results. The first, Figure 6, is an air density contour plot at 10 ms after detonation of the explosive. As the air shock exits the donor chamber, it expands into the main tunnel in both directions. The shock travelling toward the back of the tunnel must first turn a corner and is much weaker and slower than the shock front travelling toward the tunnel exit. By 10 ms, the outward moving shock has travelled to a distance of about 12 meters from the tunnel exit. It has also turned the corner into the first bay and is within two meters of the back wall of that chamber. The backward-moving shock has propagated about 8 meters toward the back of the main tunnel and is just entering the third bay.

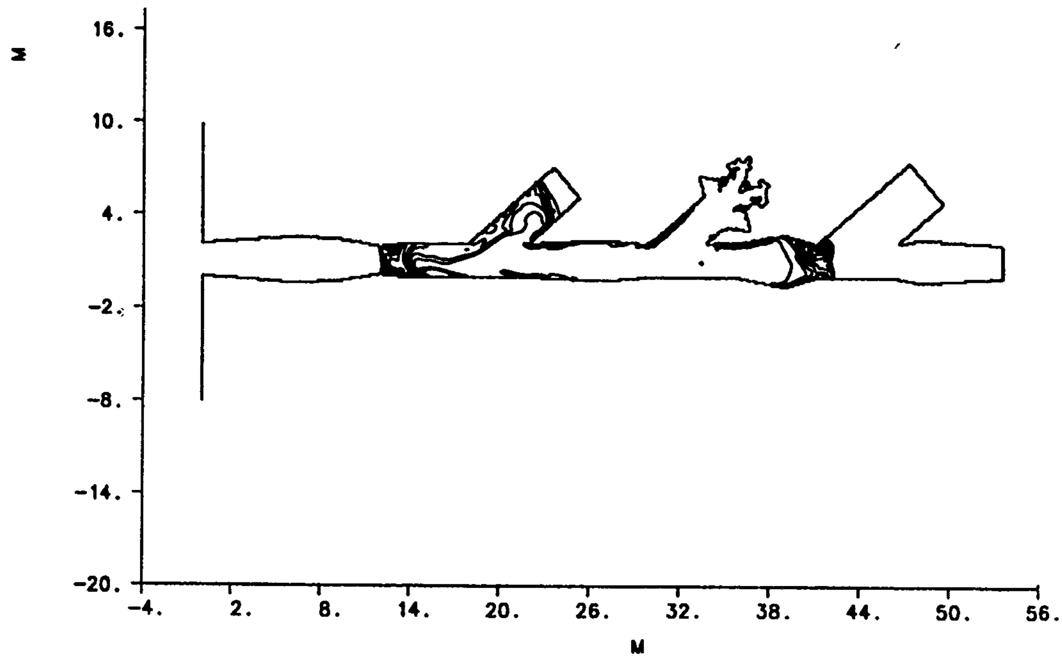

Figure 6. Air density contour plot at 10 msec from pre-test interior propagation calculation.

It is evident from the figure that the airblast incident on the side walls of the donor bay is of sufficiently high pressure to convert the material island zones in the vicinity from solid island zones to hydrodynamic granite zones. Pockets of hydrodynamic granite are formed on the side walls, directly adjacent to the charge position, and in the back corners of the donor chamber. The pockets in the back corners appear because of high

pressures from converging shock waves in these corners. The granite within the four pockets has been compressed and the walls of the chamber have been deformed by the high pressures. The mass of the converted granite is still present in these small pockets. The hydrodynamic granite in the pockets is treated as a fluid, with a density of approximately 2900 kg/m^3, for times after conversion from island cells. Pressures within the donor chamber fall quickly below the yield strength of the granite, and further conversion of granite does not occur beyond the time shown. Note, however, that the pocket of fluid granite on the right-side wall of the chamber almost penetrates to the wall of the main tunnel.

Figure 7 is a pressure contour plot at 40 ms from the first phase of the exterior calculation. The shock front has exited the tunnel and extends to a maximum distance of about 18 meters from the tunnel exit. The cylindrical configuration requires that the central axis be plotted vertically, so the tunnel has been rotated 90°. The portal is at bottom left and the left side represents the ground plane. Gravity effects are ignored. The shock exiting the tunnel has travelled around the opening and is now propagating up the hill over the tunnel. The figure reveals the decrease in peak pressure at the shock front as the angle changes from 0 degrees (straight out the tunnel) to 90 degrees.

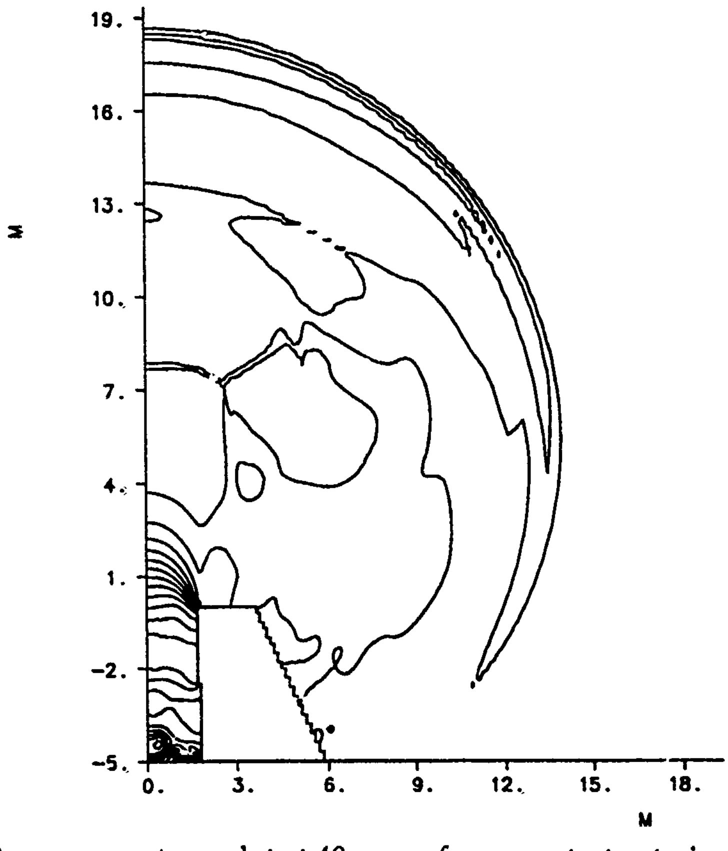

Figure 7. Pressure contour plot at 40 msec. from pre-test exterior propagation calculation.

Exterior shock propagation was calculated to a time of 400 ms. By this time the shock front has reached a distance of about 150 meters from the tunnel portal and has exited the mesh at the right boundary. Stations placed in the mesh on radials extending from the tunnel portal at increments of 15 degrees were used to construct peak pressure versus range plots of the external airblast. Additionally, the massless tracer particles used to simulate smoke puffs were tracked for the duration of the calculation. These data are compared later with test data.

3.2 Post-Test Calculations

Preliminary comparisons of overpressure waveforms with test data revealed some differences between the calculated and test results. These differences were thought to be caused by variations between the actual and planned tunnel system profiles, and by the fact that the pre-test calculation had been run with ambient air at sea level. The variations are attributed to modifications of the walls caused by previous detonations in the tunnel and to the limitations of mining techniques. As previously mentioned, the difference in internal volume amounted to some 15%. Figure 8 illustrates the magnitude of the differences in the donor bay.

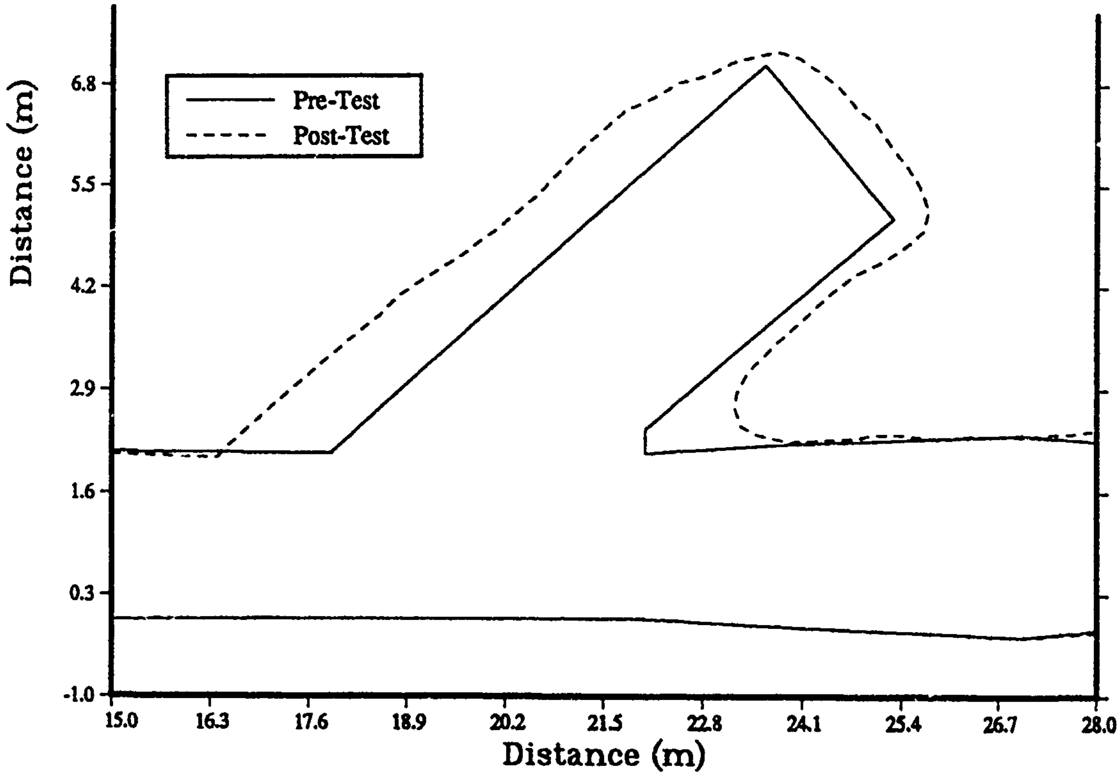

Figure 8. Enlarged view of the donor bay showing differences between configurations used for pre- and post-test calculations.

In all other respects, the pre- and post-test calculations were identical. However, because the volume is larger in the post-test configuration, there are significant differences between the two sets of results. The pressure incident on the side walls of the donor chamber in the post-test case is near or below the yield stress of granite, and therefore very little conversion of material island cells to hydrodynamic granite occurs. This is illustrated in Figure 9, an air density contour plot at 10 msec which is directly comparable to the pre-test plot shown in Figure 6.

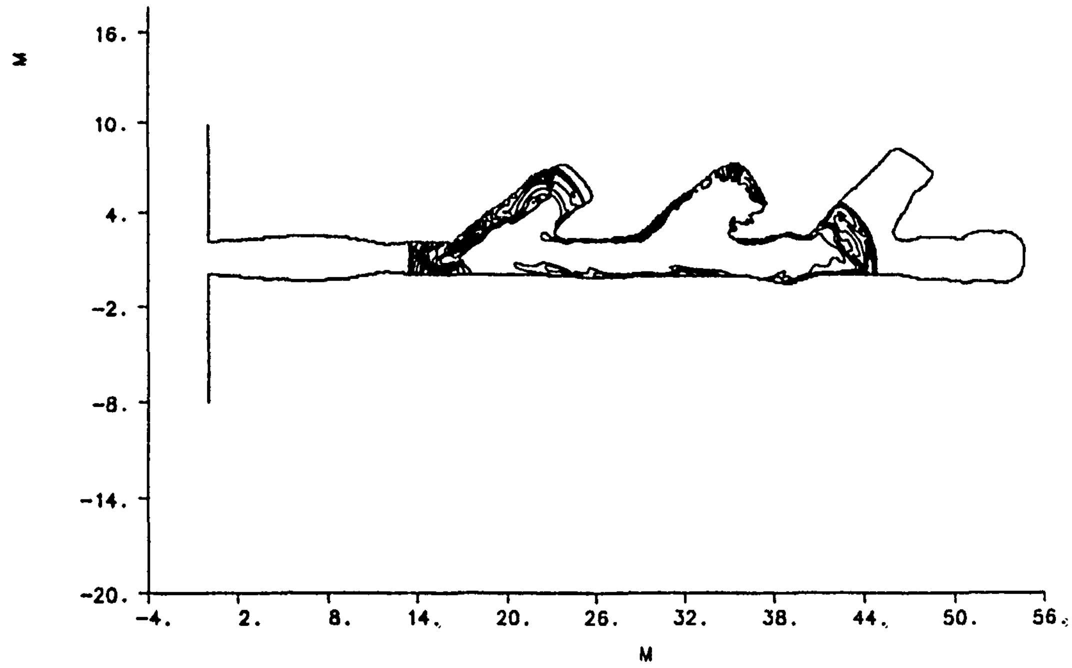

Figure 9. Air density contour plot at 10 msec from the post-test interior propagation calculation.

Differences can be seen in Figure 9 in the location of the shock front at various points within the tunnel system. The shock moving toward the back of the tunnel system has travelled further than in the pre-test calculation. This is because the rounded corners of the donor chamber allowed the airblast to exit the chamber earlier. The shock moving toward the portal is travelling more slowly than in the pre-test calculation and is about 1.5 meters further from the exit. This occurs because the pressure at the shock front is lower, which is a result of the expansion into the larger volume of the donor bay. The lower ambient pressure also causes lower peak pressures at the shock front, which further reduces the propagation speed of the shock front.

The post-test calculation was run to a time of 30 ms after detonation. This time was sufficient to obtain complete airblast waveforms at all stations within the tunnel system.

Of greatest interest were the stations near the tunnel exit. It was hoped that the overpressure records at these locations would have significantly lower peaks than those of the pre-test calculations. Although there were favorable differences at stations near the charge, by the time the shock front reached the portal, the differences were not as large as had been anticipated, and hence a post-test exterior calculation was not undertaken. The results of a few of the overpressure waveform comparisons are documented in the next section.

4. Comparisons of Calculated Results with Test Data

4.1 Airblast Station Records

In both the pre- and post-test calculations, stations were placed at all of the internal and most of the external test gage positions. The calculational stations recorded all hydrodynamic quantities for the duration of the calculations. In addition, several derivable quantities, such as temperature and stagnation pressure, are available. This section presents comparisons of selected internal and external airblast measurements. The entire set of comparisons is included in our final report, which is in preparation and will be available soon.

The airblast gage designated AB4 was located 25.9 meters from the portal in the center of the main tunnel. It is halfway between the first and second (donor) bays. Figure 10 is a comparison of pre- and post-test calculated results with the experimental record obtained at this location. The pre-test calculation shows a first peak that is higher than the data. Several secondary shocks occur as the pressure decays to a level ultimately somewhat below the data. The post-test calculation provides better agreement. The first peak in this case is only 30% higher than the data and is followed by several secondary shocks of increasing magnitude to a maximum value of 3.2 MPa. The experimental data exhibits the same structure but the peaks are lower. A second series of peaks occurs at between 12.5 and 16 ms. During this portion of the waveform, experimental and calculated pressures are in good agreement. After 16 ms, the post-test calculation falls to a pressure level lower than that of the experimental results.

Gages were located in all three of the storage bays. The one in the bay nearest the portal was designated AB9. The comparison is shown in Figure 11. The data and calculational records all show complex waveforms caused by multiple reflections from the side and back walls of the chambers. It is apparent, however, that the post-test calculation provides much better agreement with the data than does the pre-test calculation. Aside from the initial peak pressure, the general behavior of the data is well matched by results of the post-test calculation. We should mention that the calculated records have been shifted in time to match the arrival times of the data. For AB4, this shift was about 6 msec; for AB9, it was 8 msec.

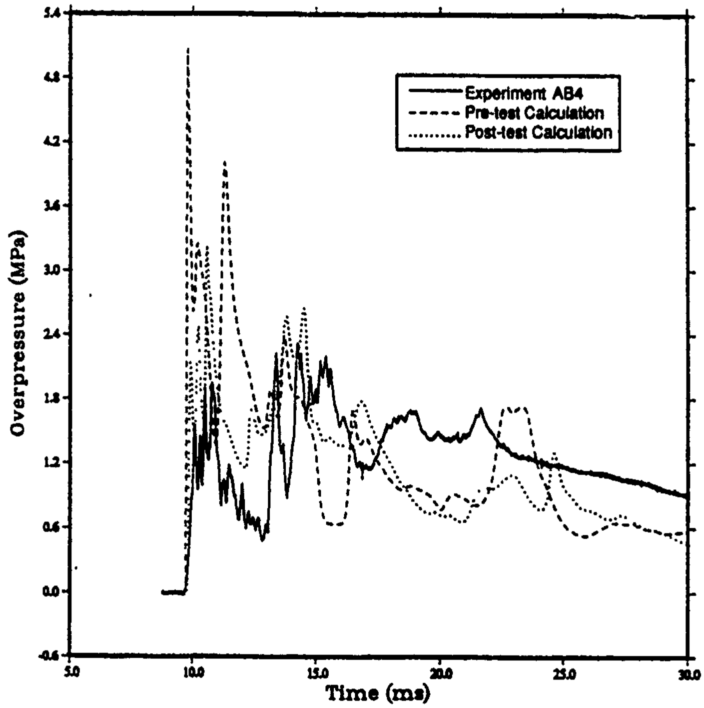

Figure 10. Comparison of pre- and post-test calculated station records with data from AB4, located in the main tunnel between the first and second storage bays.

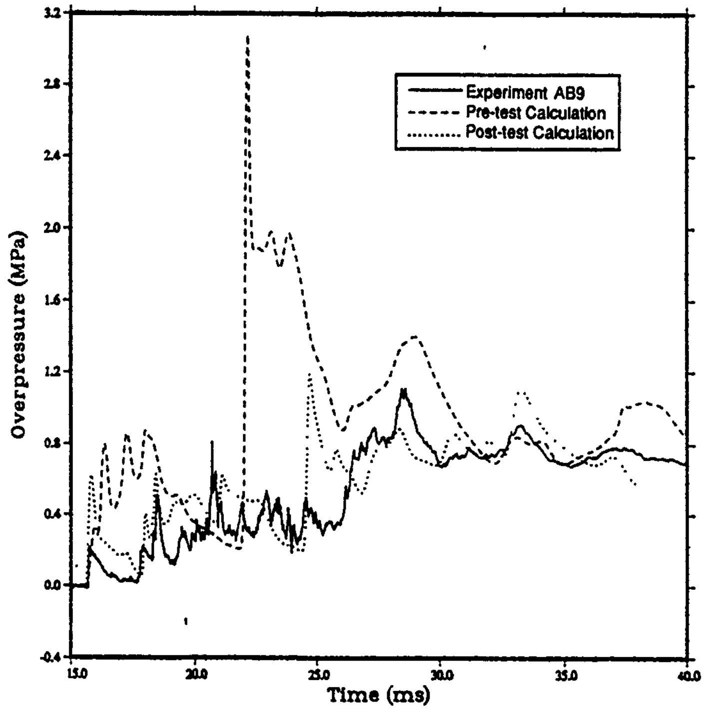

Figure 11. Comparison of pre- and post-test calculated station records with data from AB9, located in the first storage bay.

Figure 12 is a plot of the arrival time shifts required to match both the pre- and post-test calculated results with experimental arrival times at each of the gage positions along the main tunnel and on the 0° radial beyond (outside) the portal. Positive values indicate that the calculations were early, hence the amounts shown were added to the calculated arrival times for the waveform comparisons. The two calculations required the same shift, 6 msec, at a distance of 25 m. Distances in this and the next plot are measured from the portal, so 32 m corresponds to the position just outside the donor bay. This is the position closest to the charge (the pre-test calculation did not include a station at this point). The 6 msec difference may indicate that the experimental "det zero" signal occurred earlier than the actual charge detonation, or that there was a difference between the actual detonation and the calculated ideal detonation.

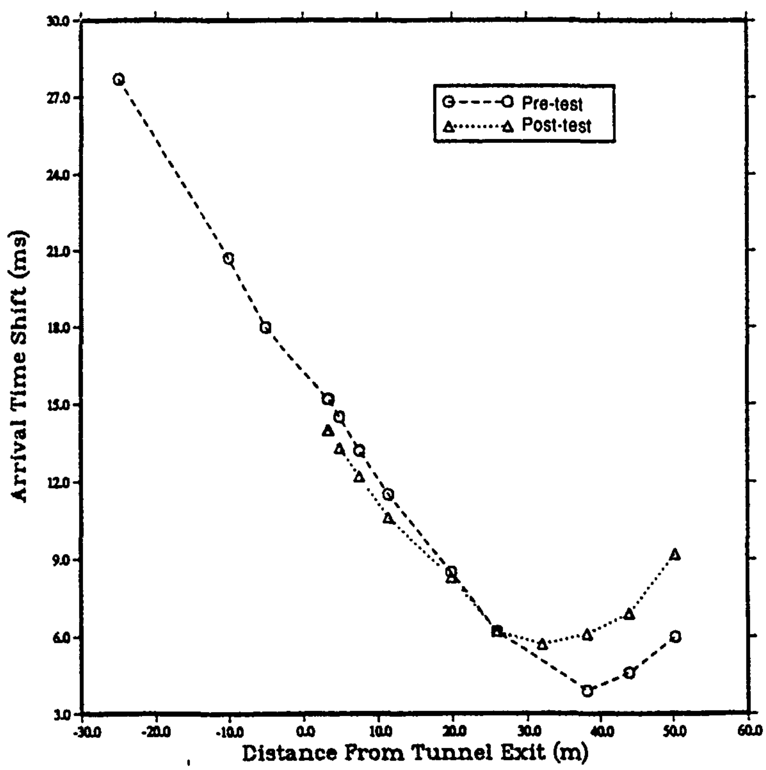

Figure 12. Shift in pre- and post-test calculated arrival times required to make them agree with those from the experiment. Distances are measured from the portal, and negative values are outside.

In either direction from the 32-m point, the arrival times for the post-test calculation move further ahead of the experimental values. This follows from the fact that the pressures are higher in the calculations, and hence the shock speeds are greater. The shift is only about 4 msec in the pre-test case at 40 m, probably because the acute corner of the donor bay was included for the pre-test configuration, delaying direct propagation of the shock to this point. Otherwise, the arrival time differences increase with range as in the post-test case.

Comparisons of peak overpressures as functions of distance from the tunnel portal are plotted in Figure 13. This figure includes only calculational stations and experimental data located along the centerline of the main tunnel. In this plot, as in the previous one, the portal is at 0, and positive values are inside; negative distances indicate exterior locations. At 32 m, the post-test calculation shows a result close to that of the experimental data. However, the calculated peak overpressures do not decay as rapidly as do the experimental results as we move to the left toward the portal. In both the experimental and the calculated data, there is a higher peak pressure at 3 m than at 6 m. This is probably due to a constriction in the tunnel cross section at this point. Beyond the portal, the peak pressures drop dramatically as the shock wave expands into the exterior region.

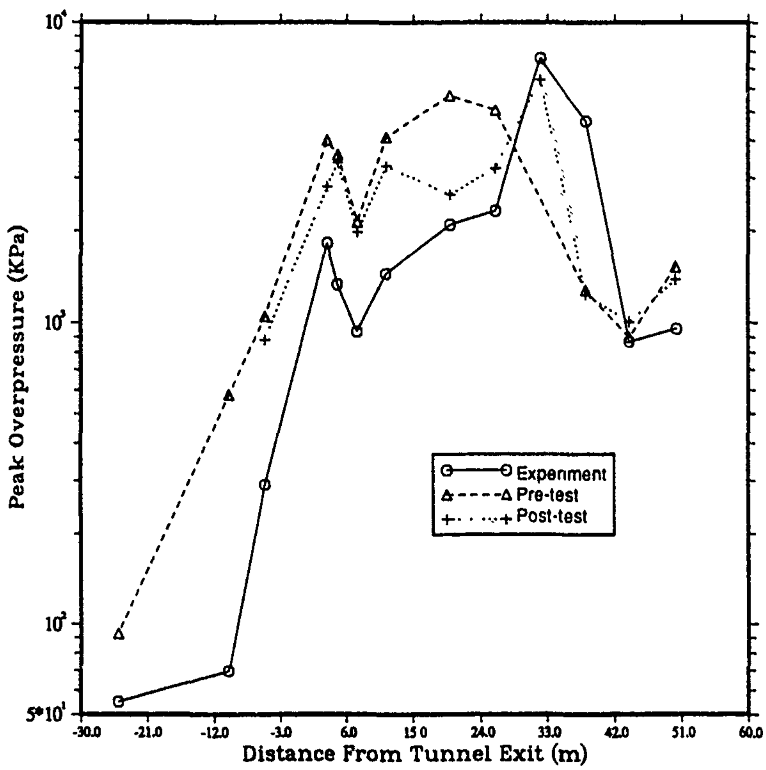

Figure 13. Comparison of pre- and post-test calculated peak overpressures with those from experimental data. Distances are measured from the portal, and negative values are outside.

Toward the back of the tunnel, the calculations seem initially to decay more rapidly than the test data. There is some indication that the 38-m gage may have registered an erroneously high value, or the configuration may have been more confined than was modeled in the calculation. The peak pressure at the 44-m station is excellent for both calculations; whereas at 50 m it is high. This latter peak pressure arises from the shock

after reflection at the back of the tunnel. Both calculations predict a strong reflection, while the measured value is lower.

The external airblast experimental waveforms were also compared to the pre-test calculated results. One of these comparisons, at 25 m from the portal on the center line, is shown in Figure 14. The difference in peak overpressure is about a factor of two on the safety conservative side. Some smearing of the shock front, due to the large computational zones in this region, is evident. The time shift used to match arrival times for this record was 28 msec.

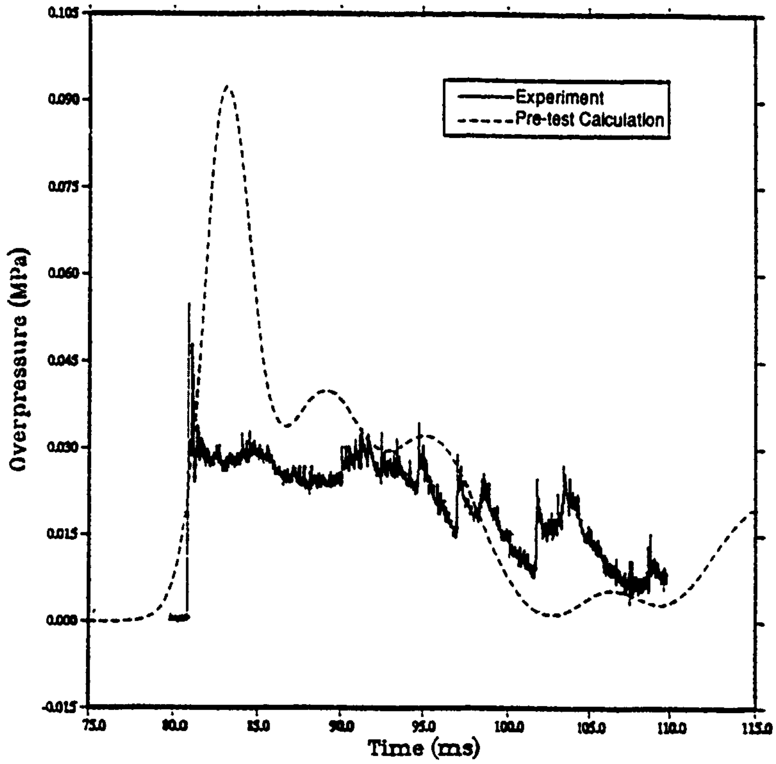

Figure 14. Comparison of pre-test calculated station records with data from AB22, located 25 m from the portal, exterior to the tunnel.

Additional stations were placed in the external airblast calculations along radials originating from the tunnel exit at increments of 15 degrees. These stations were used to create the peak overpressure versus range plot in Figure 15. In this plot, the zero-degree line is the line of stations directly in front of the tunnel exit. This line has the highest peak pressures, as expected. The pressure drops as we move toward the 90-degree radial. Three of the radials cross the 50-mbar line. The crossing point is 111 meters at 90 degrees, 113 meters at 75 degrees, and 130 meters at 60 degrees. The other attenuation curves can be extrapolated to 50 mbars also. The data can then be used to construct safety-conservative exclusion contours for use of the area modeled by this configuration.

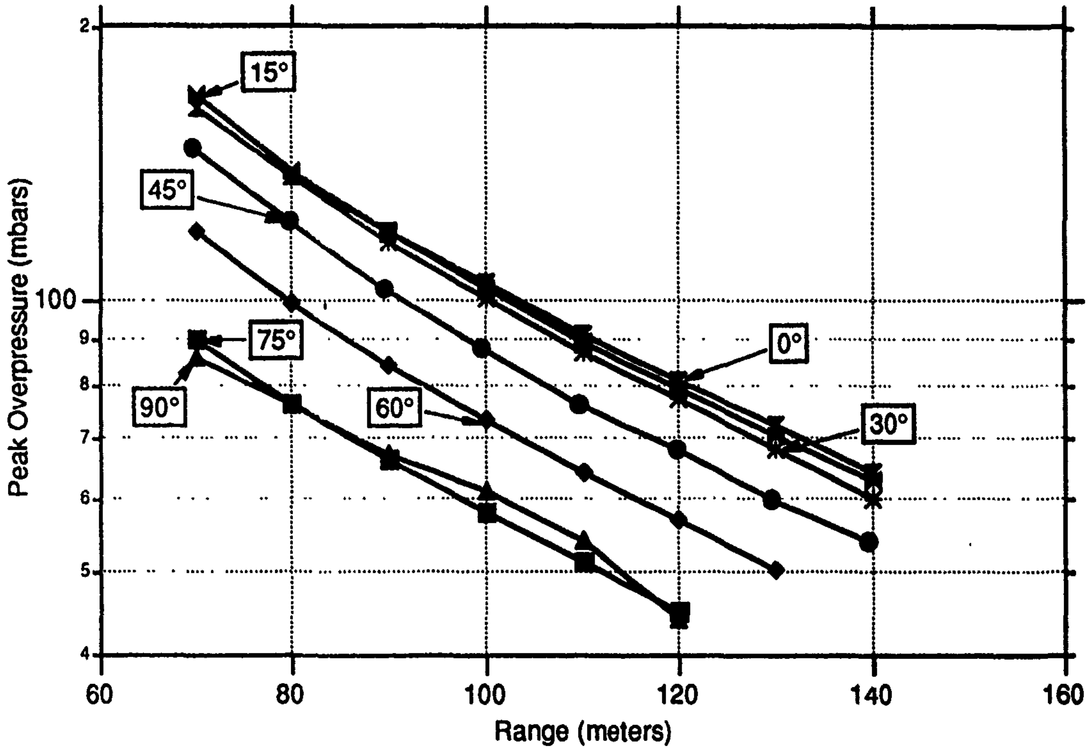

Figure 15. Overpressure attenuation curves as functions of range and angle from the exterior calculation.

4.2 Smoke Puff Comparisons

An array of smoke trails was fielded[1] in the experiment in the region just outside the portal. The motion of the smoke trails as the shock wave engulfed them was recorded using high-speed photography. Positions of the trails were as illustrated in Figure 16, and lines of massless tracer particles were included in the calculation at the same locations to model the trails.

Comparisons have been made of the calculated particle positions as functions of time with the positions of key identifiable features of the smoke trails. Nine intersection points, shown at the small circles in Figure 16, have been followed and compared in this manner. The first four points are those at which the smoke trails intersect a 30° line from the portal. For these, motions along the 30° line have been recorded. The other five points are intersections of the trails with a horizontal line two meters above the surface. Horizontal motions have been recorded in these cases.

[1] Fielding of smoke trails and analysis of flow fields from the photographic results was accomplished by John Dewey and Doug McMillin, University of Victoria.

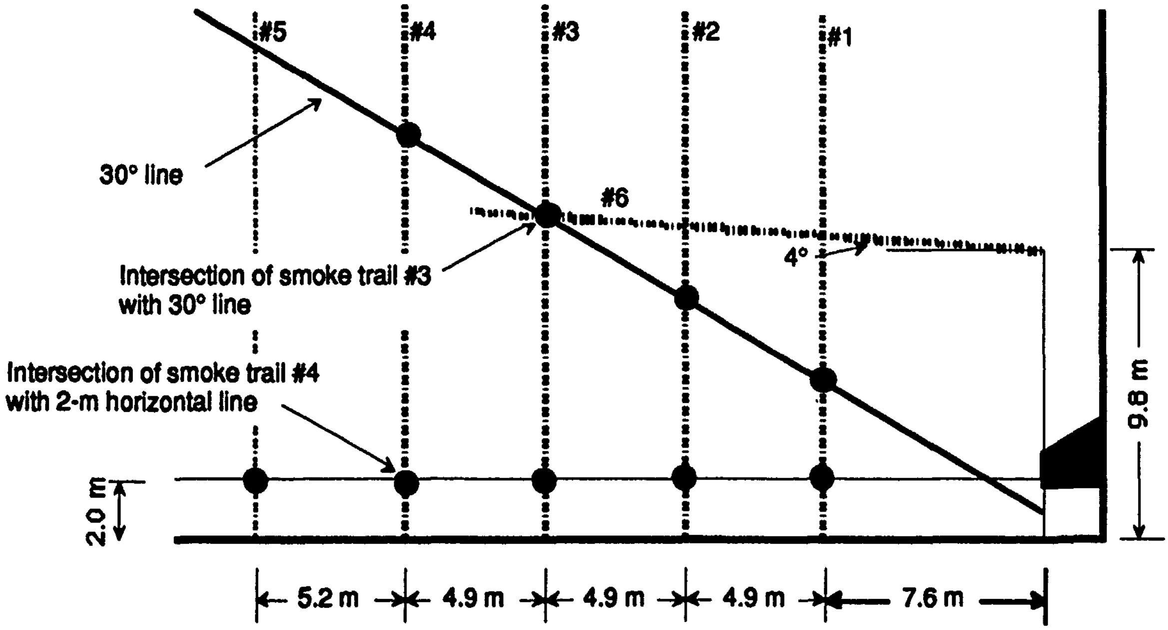

Figure 16. Smoke trail/massless tracer particle configuration showing intersection points at which experimental data is compared with calculational results.

Figure 17 is a comparison of the experimental and calculated results for the positions on the 30° line, as functions of time. As for the waveforms, the times have been adjusted to account for the differences in arrival time of the shock at the positions in question. The comparison shows that the calculated particle motions are in good agreement with the test data. Each of the trajectories has the same basic profile. Each particle remains essentially stationary until arrival of the shock front, then is displaced outward as the shock wave passes its position. As the result of vortex formation at the edge of the jet of air and detonation products emerging from the portal, the particles later move back toward their original positions. The trail at 25 meters shows some initial drift; this is probably due to ambient air motion.

Figure 18 is a similar set of comparisons for the points on the horizontal line two meters above the surface. As before, agreement is excellent. Motion for the 7-m point is initially more pronounced in the calculation. This is in agreement with the results cited earlier, in which the emerging calculated shock wave was stronger than that observed.

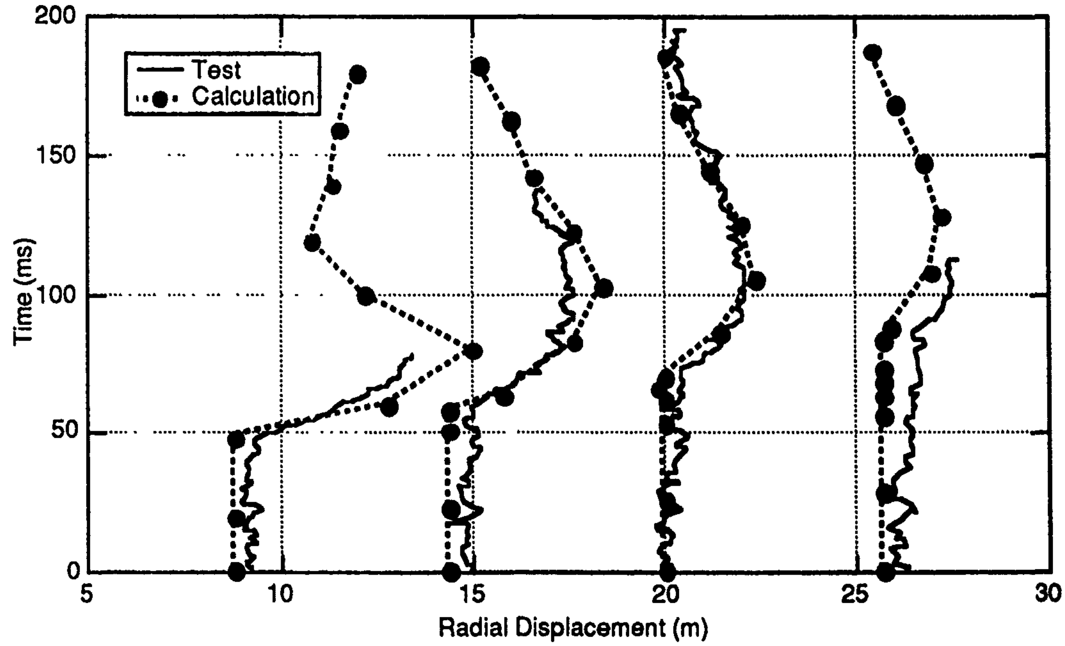

Figure 17. Displacement along 30° line of four smoke trail features; comparison of experimental and calculated data.

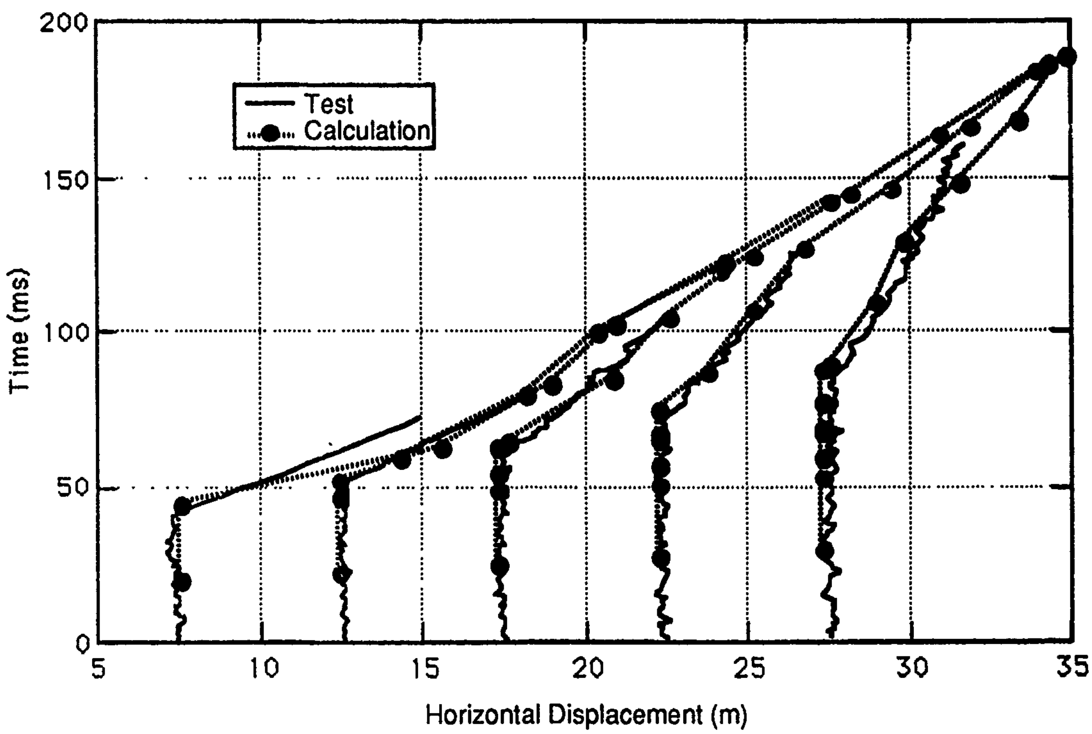

Figure 18. Horizontal displacement of five smoke trail feature, two meters above surface; comparison of experimental and calculated data.

5. Summary and Conclusions

The hydrodynamic SHARC code calculations provide a full set of parameters at a number of locations, which can be compared with various kinds of experimental results. We have discussed only overpressure records and smoke trail results in this paper, but other types, including temperature records and fragment velocities, can be obtained.

A large number of hydrocode runs have been made over the years of explosions in confined spaces, with varying degrees of success. The current calculation set for the Camp Stanley configuration is similar to others in that it tends to be safety conservative; that is, to predict peak overpressure values that are higher than those observed. Several points are noted:

1. Calculations of tests in chambers with non-yielding, smooth walls, such as steel pipes, tend to produce results in good agreement with test data.

2. Calculations of tests in geologic materials, like limestone or granite, with walls produced by mining, tend to be safety conservative if a state-of-the-art, second-order hydrocode like SHARC is used.

3. It is important to prepare a calculational model for the interior space which is as accurate as possible. Internal volume should be close to the as-tested value.

Over the years, we have attempted to produce better results by refining our models. Some of the things we have tried have worked well, others not so well. The material island concept was developed specifically for the purpose of improving the interior wall response by allowing walls to absorb energy and to deform under high pressure, and we feel that it provides a reasonable approximation in most cases. It is certainly possible that "tweaking" the conversion yield strength and the compressibility values for the rock equation-of-state could provide improved agreement. However, this would need to be done specifically for each test site, and would be of limited value for predictions on untested sites.

Currently, we are considering methods of adding turbulence and wall roughness modeling for tunnel interiors. We now model large-scale irregularities by configuring the outline of the tunnel, but there is an additional roughness on a scale which is less than the dimension of the calculational zones. Models for treating this roughness, and the turbulence arising from it, currently exist in SHARC, and have been used with good success to model precursed airblast over rough, flat surfaces. The models, however, have only been implemented to work at calculational mesh boundaries. In order to use the models for tunnel interiors with irregular surfaces, wall roughness functions assignable to the surfaces of internal computational cells need to be incorporated in the coding. The implementation of this capability, and the testing of it against available test data, constitutes the next major thrust of our internal airblast computational effort.

GROUND MOTIONS FROM DETONATIONS IN UNDERGROUND MAGAZINES IN ROCK

Twenty-Fifth DOD Explosives Safety Seminar

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GROUND MOTIONS FROM DETONATIONS IN UNDERGROUND MAGAZINES IN ROCK

by
G. W. McMahon

This paper discusses the problem of determining ground motions resulting from the detonation of munitions stored in underground magazines in rock. Six sets of ground motion test data from decoupled detonations in rock are compared, including the China Lake Shallow Underground Tunnel/Chamber Test (1989) and the Camp Stanely Validation Test (1990). The data are presented in two consistant forms which are used to discuss analysis and prediction techniques. Current techniques for predicting ground motions from decoupled events are compared and a peak particle velocity prediction equation based on a fit of available data is presented.

GROUND MOTIONS FROM DETONATIONS IN UNDERGROUND MAGAZINES IN ROCK

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INTRODUCTION

The U.S. Army Engineer Waterways Experiment Station (WES) is currently conducting a research program to investigate underground munitions storage concepts. The goal of this research effort is to investigate techniques for mitigating the blast effects (primarily, airblast and debris) that would escape out the entrance portal in the event of an accidental detonation of munitions stored in individual magazine chambers. A secondary concern is the effect on nearby structures of direct-induced ground motions generated by such an explosion. If the research program is successful in developing designs which significantly reduce external airblast and debris hazards, then it appears likely that the controlling blast effect for establishing hazard areas around such facilities will be ground motion. The purpose of this paper is to review available test data, including recent data from actual blast effects tests for underground munitions storage facilities, and current techniques available for calculating ground motion levels from decoupled detonations in rock.

BACKGROUND

The detonation of a store of munitions in an underground facility represents a complex explosion environment in which a number of parameters have a significant

affect on the resulting long-range ground motions. The dominant factor is the amount of explosive contained in a storage chamber of given volume, referred to as the loading density. Other factors include the type and distribution of explosives (distributed along the length of a long chamber or concentrated), the amount of venting between the chamber and tunnel system, and the properties of the rock surrounding the facility. In general, the only factors which are accounted for in current prediction techniques are the loading density and the properties of the material, with the latter limited to material constants.

A ground motion hazard criterion is usually defined as a peak particle velocity at which a certain level of damage is expected. The current U.S. (DOD 6055.9-STD, 1984) and NATO (NATO Document AC/258-D/258, 1991) explosives safety standards quote 11.5 cm/sec and 23 cm/sec in soft and hard rock, respectively, as the maximum acceptable levels for inhabited buildings.

Techniques for predicting peak particle velocity are generally of two types. Each takes a different approach to account for charge decoupling (i.e., the fact that there is an air void between the explosives and the surrounding rock medium). The first relies on an estimate of the initial cavity pressure to calculate the maximum strain or velocity of the cavity wall, which is then used as an initial condition for calculating velocities at increased ranges. This technique was used (Drake, 1974) to develop an elastic solution to a spherical one-dimensional approximation of the problem. Another equation was developed (Smith, 1989) based on 1:75 scale model test data, using the same technique.

The second type of prediction technique relies on fully-coupled peak particle velocity data, and uses a reduction or decoupling factor to account for the decoupled charge configuration. The decoupling factor is defined as the ratio of peak particle velocity at a given distance from a decoupled detonation to that from a fully-coupled detonation of the same charge weight. The velocity from a decoupled detonation is calculated from the equation:

$$V_d = D * V \tag{1}$$

where V_d is the decoupled velocity, D is the decoupling factor, and V is the fully-coupled velocity. This formula is used in both the U.S. and NATO standards. The benefit of this technique is that equations that predict fully-coupled motions can be used in conjunction with the decoupling factor to predict motions resulting from decoupled charge configurations. The drawback is that little data exits to verify that the decoupling factor is accurate.

Dimensional analysis and cube root scaling (Ambraseys and Hendron, 1968) indicate that empirical equations derived from fits to peak velocity data should be of the form

$$\frac{V}{c} = K\left[R\left(\frac{\rho c^2}{W}\right)^{1/3}\right]^n \tag{2}$$

where V is the peak particle velocity, c is the seismic velocity of the rock, ρ is the mass density of the rock, W is the charge weight, R is the range, and k and n are constants determined from a fit of the data. Odello (1980) indicates that the equations in the U.S. and NATO standards, from which the Inhabited Building Distance equations for ground shock are derived, originate from Mickey (1964), and are of the form

$$V = K\left(\frac{R}{W^{4/9}}\right)^{-2/3} \tag{3}$$

where K is a constant dependent upon the medium and V, R, and W are as previously defined. This equation is not consistent with cube root scaling or dimensional analysis.

COMPARISON OF DECOUPLED DATA WITH PREDICTION EQUATIONS

A search for available data from decoupled underground detonations in rock revealed six sets of data, listed in Table 1. Four of the sets represent data from actual underground magazine tests; the KLOTZ II test (Hultgren, 1987, and Vretblad, 1988), the WES 1:75-scale model tests (Smith, 1989), the China Lake shallow underground magazine test (Joachim, 1990), and the Camp Stanley 1/3-scale validation test (Ensco, 1991). The Cowboy test data (Murphey, 1960) were gathered from a series of experiments designed to evaluate the extent to which underground explosions could be concealed by detonating charges in chambers. The Cowboy data are unlike the others, since both the charges and chambers were spherical and non-vented. The final set of data was collected by the U.S. Bureau of Mines (Atchison, 1964). The Bureau of Mines tests used elongated charges placed in vertical bore holes. The KLOTZ, Cowboy and Bureau of Mines data included both fully-coupled and decoupled data, allowing calculation of decoupling factors.

The above data are presented in two forms, such that comparisons can be made to the two types of prediction equations described previously. In order to compare the data to Drake's and Smith's equations, the decoupled velocity data were normalized by the chamber wall velocity, which was calculated from the equation

$$V_c = \frac{1000 * P_o}{\rho c} \tag{4}$$

where V_c is the peak particle velocity (m/sec) of the chamber wall, P_o is the maximum gas pressure (MPa) in the chamber, ρ is the mass density of the rock (kg/m^3), and c is the seismic velocity of rock (m/sec). This is an approximation based on one-dimensional elastic plane wave theory, which is not strictly accurate for the data presented, especially for higher loading densities. The chamber pressure (MPa) can be estimated (from Smith, 1989) by the relation

$$P_o = 1.11\left(\frac{W}{V_1}\right) \tag{5}$$

where W/V_1 is the loading density (kg/m^3). The range is normalized by dividing by the chamber radius. The data from all six test series are plotted together in Figure 1, along with Smith's (1989) and Drake's (1974) prediction equations. Considering the range of test conditions, loading densities, rock types, explosive types and configurations, and measurement types, the scatter in the data are quite acceptable.

Smith's (1989) prediction equation was derived as an upper bound of the data from the WES 1:75 scale model tests, and from some of the Bureau of Mines tests. The equation has the form:

$$\frac{V_d}{V_c} = 0.85\left(\frac{L}{A}\right)^{1.5}\left(\frac{R}{A}\right)^{-2} \tag{6}$$

where V_c is as previously defined, V_d is the decoupled velocity, L is the chamber length, A is chamber radius, and R is range, all in compatible units. The plot of Equation 6 in Figure 1 is with respect to the L/A ratio of the WES 1:75 scale model tests, which was 23.6. The other tests had L/A values ranging from 1 to 16.8 (see Table 1). The fact that Equation 6 provides a reasonable upper bound fit to all the data indicates there may not be a strong dependence upon L/A for these data.

Drake's (1974) equation is of the form:

$$\frac{V_d}{V_c} = \frac{A^2}{R^2} + 0.0128\left(\frac{P_e}{P_l}\right)^{2/3}\frac{A}{R} \tag{7}$$

where V_d, V_c, R, and A are as previously defined, P_e is the explosive density, and P_l is the chamber loading density. The cavity wall particle velocity is estimated by Drake (1974) as

$$V_c = V_o \left(\frac{P_l}{P_e}\right)^{1.2} \tag{8}$$

where P_l and P_e are previously defined and V_o is the peak particle velocity of the cavity wall for a fully-tamped charge, which may be estimated from

$$\frac{V_o}{c_e} = 0.75 \left[1 + \frac{(\rho c)_r}{(\rho c)_e}\right]^{-1} \tag{9}$$

where c_e is the detonation velocity of the explosive, $(\rho c)_r$ and $(\rho c)_e$ are the impedances of the rock and explosive, respectively. Equation 7 cannot be plotted uniquely in Figure 1 due to a nonlinear dependence on the loading density. The plot of Equation 7 in Figure 1 is with respect to the Cowboy test parameters (i.e., rock and explosive properties, Nickols, 1960) and a loading density of 16.4 kg/m^3. The equation fits the Cowboy data and the Bureau of Mines data quite well, but falls below all the other data sets, for all ranges of R/A. Plots of Equation 7 for larger loading densities would fall below this line, while those for lower loading densities would fall above it.

The six data sets were also represented in another form in order to compare them to prediction techniques which rely on scaled distance and decoupling factors as input parameters. In order to collapse the data for comparison at various loading densities, the decoupled velocity was divided by the decoupling factor, which then essentially represents the decoupled data as fully-coupled data. The decoupling factor used to normalize the test data was derived from the plot of available data shown in Figure 2. The data are calculated from peak velocity measurements, recorded at the same distance from both a fully-coupled and a decoupled charge of the same weight, and in the same medium, using the relation

$$D = \frac{V_d}{V} \tag{10}$$

where D is the decoupling factor, V_d and V are as previously defined. The decoupling factor is represented as a function of the relative loading density, which is the actual loading density divided by the density of the explosive material (see Figure 2). This allows data from various explosive types to be presented on the same plot. A fit of the data provided an expression for the decoupling factor as

$$D = \left(\frac{p_l}{P_e}\right)^{.38} \tag{11}$$

This expression takes into consideration data from four sources, but still represents relatively few data points. The decoupling equation used in the U.S. and NATO standards is also plotted in Figure 2, in terms of a relative loading density, for comparison. This equation was derived from only the Cowboy data, and ignored the data points below 16 kg/m^3, which equates to a relative loading density of 0.0016 for the Cowboy explosive (Odello, 1980).

The six sets of data are plotted in Figure 3 in terms of dimensionless variables. This representation accounts for variations in loading density through the use of the decoupling factor, and for variations in charge weight and materials through the use of dimensionless variables. The scatter of the data is less than the previous representation, and again is reasonable for the variations in the test parameters included. A fit of these data provides an equation of the form

$$\frac{V_d}{Dc} = 910\left[R\left(\frac{\rho c^2}{W}\right)^{1/3}\right]^{-1.70} \tag{12}$$

For comparison, the equation for the fully-coupled detonations (developed from the

KLOTZ tests) is also plotted in Figure 3. This equation is an upper bound to all the data and, as expected, provides a good fit to the KLOTZ data. The equations in the U.S. and NATO standards which are used to define the inhabited building distance for ground shock cannot be compared to the data in this form, since the equations are not consistent with cube root scaling.

CONCLUSIONS AND RECOMMENDATIONS

Velocity data from underground detonations of decoupled charges in rock have been presented and compared to several prediction techniques. Equations developed by Smith and Drake rely on a calculation of initial chamber pressure instead of a decoupling factor to account for decoupled detonations. This technique is attractive, since explosive types and geometries can be considered in a calculation of the maximum chamber gas pressure, but a more accurate technique is needed than that currently used for calculating gas pressure. An additional drawback is the simplifying assumption that elastic plane wave theory can be used to estimate the initial velocities of the chamber wall. Smith's equation provides an upper bound to the experimental data. Drake's equation requires additional properties of the explosive and cannot be directly compared with Smith's equation, but was shown to compare well with data from the decoupled tests of Project Cowboy.

A better representation of the velocity data from decoupled explosions appears to be provided by an empirical approach, with the data plotted with respect to dimensionless variables. A fit of the data provides a means to predict peak particle velocities from decoupled detonations in rock. The most useful form of the equation is

$$V_d = 910\ D\ R^{-1.70}\ W^{+0.57}\ \rho^{-0.57}\ c^{-0.13} \tag{13}$$

where V_d is the decoupled velocity (m/sec), D is the decoupling factor, R is the range

(m), W is the charge weight (Kg), ρ is the mass density of the medium (Kg/m^3), and c is the seismic velocity of the medium (m/sec).

The equation for decoupled detonations presented in this paper requires verification by additional test data. There are indications that the coupling factor may be dependent upon range from the detonation, in addition to loading density.

The above equation is a fit of predominantly radial velocity (at depth in rock) data, but also includes vertical and horizontal surface velocity measurements, and resultant motions of triaxial measurements. It is not strictly accurate to compare these various types of motions on the basis of wave propagation theory. Future testing and analysis should attempt to distinguish between these various types of motions.

ACKNOWLEDGEMENT

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REFERENCES

1. "DOD Ammunition and Explosive Safety Standards," Report No. DOD 5154.4S, Washington, DC.

2. "Ground Motion Measurements for the Camp Stanley Validation Test", Technical Report, November 25, 1991, Ensco, Inc., Springfield, VA.

3. Ambraseys, N. R., and A. J. Hendron, 1968, "Dynamic Behavior of Rock Masses," in Rock Mechanics in Engineering Practice, (K. G. Stagg and O. C. Zienkiewicz, Eds.), John Wiley & Sons, Inc., London, pp.203-227.

4. Atchinson, Thomas C., Duvall, Wilbur I., and Pugliese, Joseph M., 1964, "Effect of Decoupling on Explosion-Generated Strain Pulses in Rock", Report of Investigations 6333, Bureau of Mines.

5. Drake, J. L., 1974, "Decoupling of Ground Shock from Explosions in Rock Cavities", U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

6. Hansen, Spenst M., and Lombard, David B., 1965, "Mining by Caving with Nuclear Explosions", University of California, Lawrence Radiation Laboratory, Livermore, CA.

7. Hultgren, Staffan, 1987, "Ground Motion Measurements, KLOTZ II", Report C4:87, Royal Swedish Fortifications Administration, Eskilstuna, Sweden.

8. Joachim, Charles E., 1990, "Shallow Underground Tunnel/Chamber Explosion Test Program Summary Report", Technical Report SL-90-10, Waterways Experiment Station, Vicksburg, MS.

9. Kolsky, H., 1963, "Stress Waves in Solids," Dover Publications.

10. Merz, Hans A., 1982,"A Survey of Models for Predicting the Groundshock of Accidental Explosions in Underground Storage Facilities", minutes of the Twentieth Explosives Safety Seminar, Norfolk, VA.

11. Mickey, W. V., 1964, "Seismic Wave Propagation", Engineering with Nuclear Explosives, U. S. Coast and Geodetic Survey, Washington, D. C.

12. Murphey, Byron F., 1960, "Particle Motions near Explosions in Halite", Journal of Geophysical Research, Volume 66, No.3, Sandia Laboratory, Albuquerque, New Mexico.

13. Nicholls, H. R., Hooker, V., and Duvall, W. I., 1960, "Project Cowboy, Dynamic Rock Mechanics Investigations" APRL Report No. 38-3.2, U. S. Bureau of Mines, Applied Physics Research Laboratory, College Park, MD.

14. Odello, R. J., 1980, "Origins and Implications of Underground Explosives Storage Regulations", Technical Memorandum No. 51-80-14, Naval Facilities Engineering Command, Naval Construction Battalion Center, Port Hueneme, California.

15. Smith, Dennis R., Joachim, Charles E., Davis, Landon K., and McMahon, Gordon W., 1989, "Effects of Explosions in Underground Magazines", Technical Report SL-89-15, Waterways Experiment Station, Vicksburg, MS.

16. Vretblad, Bengt, 1988, "Data from the 1987 KLOTZ-Club Tests in Sweden," Report C3:88, Royal Swedish Fortifications Administration, Eskilstuna, Sweden.

TABLE 1 - Test Data Related to Ground Motions from Decoupled Underground Explosions

Test Series	Scale	No. Tests	Loading Density (kg/m^3)	Type of Data[a]	Range $m/kg^{1/3}$	Range R/A	L/A
Klotz	FULL	8	3.3 - 25	V_{xyz}, V_v	1.0 - 5.0	5.6 - 30.1	16.8 13.9
WES 1:75	1:75	18	1.6 - 405	S_r, V_r	0.4 - 6.3	5.2 - 31.2	23.6
China Lake	1:2	1	66.4	$S\text{-}V_v$, $S\text{-}V_h$	0.4 -14.7	5.2 - 173	7.8
Camp Stanley	1:4	1	5.2	$S\text{-}V_v$	2.7 -11.1	7.6 - 30.8	7.7
Cowboy	Full	17	0.2 - 33.6	V_r	0.6 -18.7	1.6 - 76.9	1
Bureau of Mines	-	6	197 - 352	S_r	1.5 -25.0	30 - 520	16

NOTE: [a]

V_{xy} = Three components of velocity, triaxial measurement.
V_v = Vertical velocity.
S_r = Radial strain.
V_r = Radial velocity.
$S\text{-}V_v$ = Surface velocity, vertical.
$S\text{-}V_h$ = Surface velocity, horizontal.

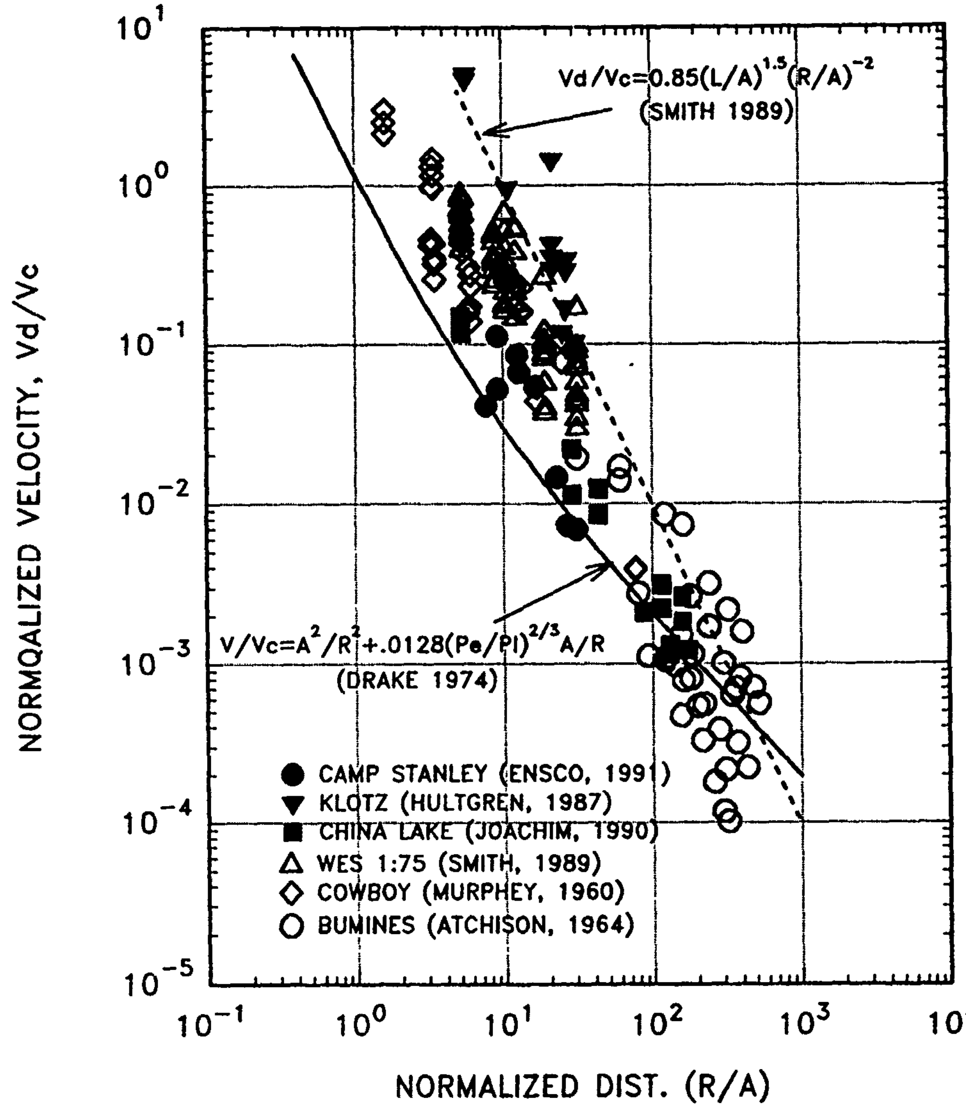

Figure 1. Comparison of Smith's and Drake's prediction equations with test data from decoupled detonations in rock. Data are plotted in terms of actual velocities divided by chamber wall velocities (normalized velocity) and normalized distance (range over equivalent chamber radius).

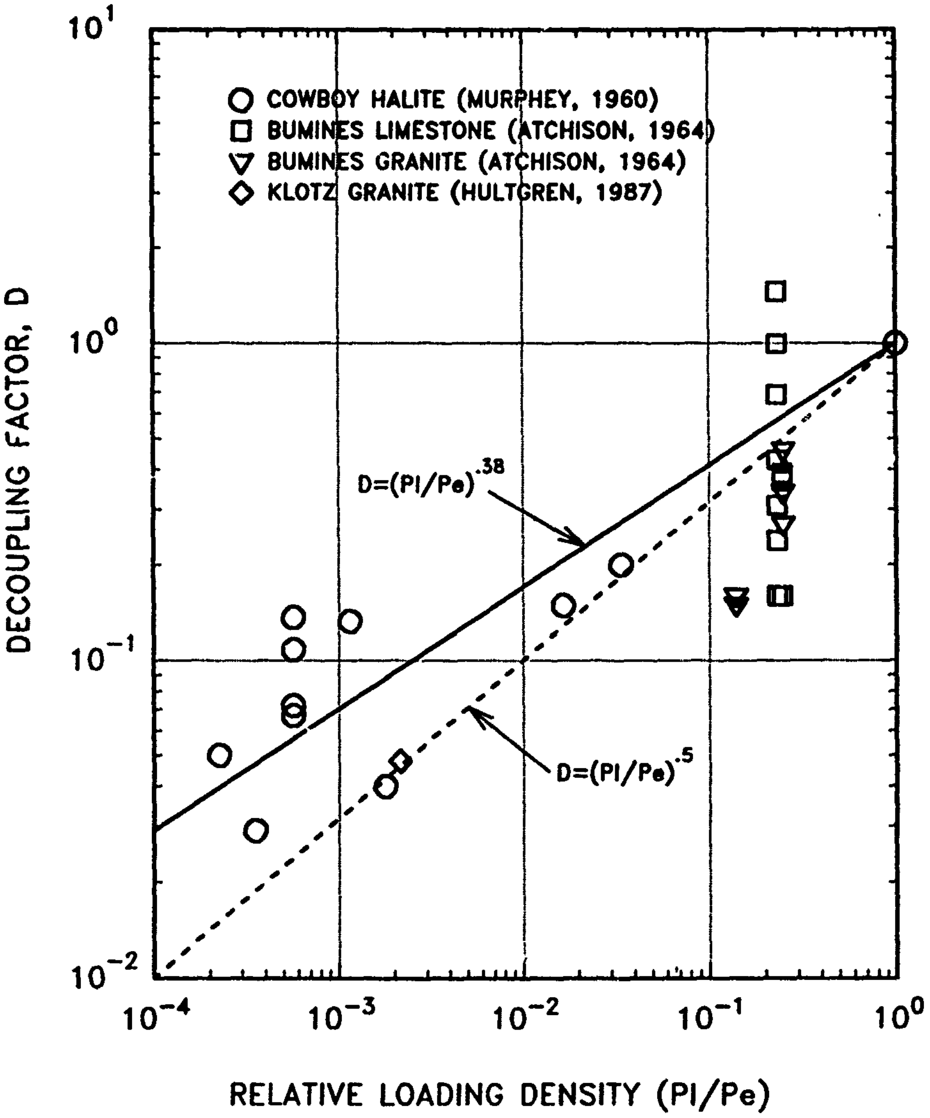

Figure 2. Decoupling factor data plotted with respect to relative loading density (actual chamber loading density over explosive material density) including a best fit expression (solid line) and the expression currently used in the U.S. and NATO safety standards.

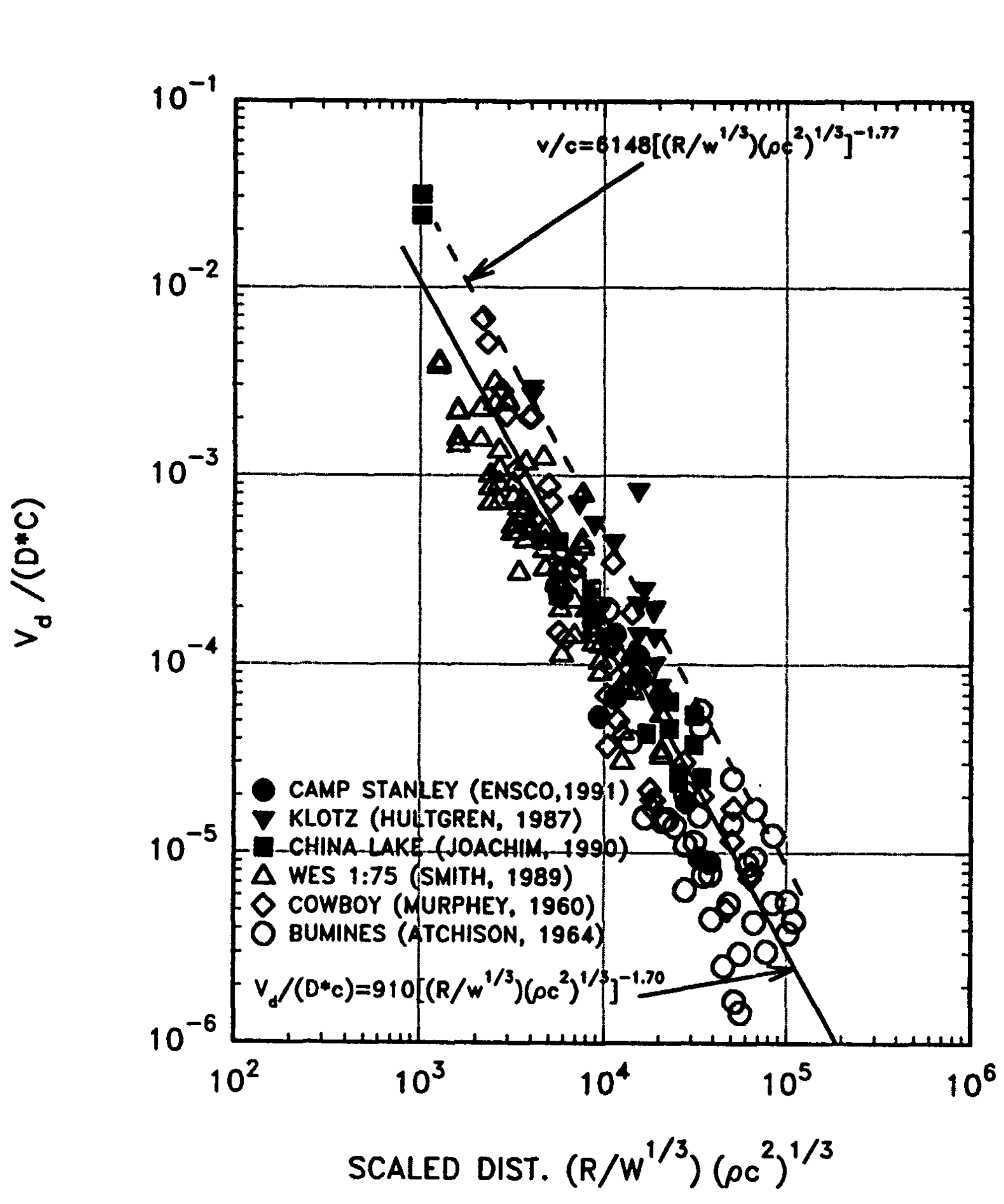

Figure 3. Peak particle velocity test data from decoupled detonations in rock plotted in terms of dimensionless variables and normalized by the decoupling factor D. Included are a best fit expression (solid line) and an expression for fully-coupled detonations (dashed line) developed from the KLOTZ tests.

BRICK MODEL TESTS OF SHALLOW UNDERGROUND MAGAZINE

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by
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BRICK MODEL TESTS OF SHALLOW UNDERGROUND MAGAZINES

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INTRODUCTION

A considerable amount of research has been performed in the last two decades to develop data and prediction methods for airblast and debris hazards from accidental explosions in underground magazines. Much of this work is concerned with detonations in magazines so deep that venting does not occur. For the shallow magazines, the effect of cover venting on reduction of external airblast was initially investigated in small-scale tests (1:25) performed in the United Kingdom (Millington, 1985). More recently, the Shallow Underground Tunnel/Chamber Explosion Test (Joachim, 1990), sponsored by the KLOTZ Club*, provided full-scale airblast and debris/ejecta data for a shallow underground magazine containing 20,000 kg, net explosive weight (NEW).

Previous explosive cratering tsts by the U.S. Army Engineer Waterways Experiment Station (WES) has indicated a definite effect of rock strength and structure (jointing) and terrain surface slope, as well as the charge cover depth, on the size and shape of the crater produced, and on the amount, direction, and velocity of ejecta thrown out (Davis, 1981, Smith, 1989 and Joachim, 1988). These results strongly imply that, at large scales where extensive volumes of rock must be moved during the venting process, the gross (as opposed to unit) strength and structure of shallow rock covers may be important factors in predicting the extent of rupture of the cover, and the ejecta hazard ranges, from site to site. This is in addition to the known problem of accounting for the variations in cover thickness and surface slope.

The 1988 Shallow Underground Test provided data for a single set of test conditions. In actual practice, however, such magazines have been constructed at sites having a wide range of rock strengths and cover thicknesses. In addition, the loading densities of the magazines differ from site to site. This paper describes a series of model tests conducted to investigate the influence that these variations would have on the external blast hazards from an accidental explosion in shallow underground magazines. This work was sponsored by the Directorate of Health and Safety, Ministry of Defence,

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* The KLOTZ Club is an ad hoc committee, representing the defense agencies of France, Germany, Norway, Sweden, Switzerland, the United Kingdom, and the United States, which sponsors research to improve the safety of ammunition storage.

United Kingdom; the Norwegian Defence Construction Service; and the Department of Defense Explosives Safety Board.

OBJECTIVE

The overall objective of the Brick Model test program was to determine the hazardous effects (airblast and debris) produced by an accidental detonation of explosive stores which ruptures the overhead cover of an underground magazine. Specific test objectives were to evaluate the effects of explosive loading density (kg of explosive per m^3 of chamber volume) and the thickness and strength of the rock cover on the external blast hazards.

DESCRIPTION OF TESTS

Three magazine models were tested, each consisting of a single storage chamber and access tunnel constructed in a large testbed of paving brick, simulating a jointed rock mass. The dimensions of the storage chamber and access tunnel corresponded to a 1:25-scale model of those constructed for the 1988 Shallow Underground Tunnel/Chamber Explosion Test. The model storage chamber was 72 cm long, with a cross-sectional area of 294.4 cm^2 (20 cm wide by 16 cm high; see Figure 1). The access tunnel was 1.0 m long with a cross-sectional area of 84.4 cm^2 (9.6 cm in height and width; see Figure 2).

Three tests were conducted. Test 1 modeled the cover depth and explosive loading density of the 1988 Tunnel/Chamber Test. Test 2 had the same cover depth, but a reduced loading density. For Test 3, the loading density was the same as Test 2, but the cover depth was increased from 48 to 86 cm.

Dynamic measurements on all tests included: (1) chamber pressures, (2) access tunnel pressures, (3) external airblast pressures, and (4) motion (acceleration) of the simulated rock mass above the chamber. The airblast and ground-motion gage locations are shown in Figure 3. Passive measurements consisted of post-test surveys of debris distributions for Test 3, and observations of the extent of cover rupture and debris throw on all three tests.

MODEL CONSTRUCTION

All models were constructed with solid paving bricks (without mortar) inside a reinforced concrete containment structure, as illustrated in Figure 4. Dimensions of the bricks were 5.8 by 9.3 by 19.7 cm. As shown in Figure 4, the bricks were laid with the wide face (9.3 by 19.7 cm) in the vertical plane, and with the long axis rotated 30° from

the vertical, in the direction of the portal. Thus, the overburden surface slope of the models was 30 degrees. A thin layer of sand was placed over the surface of the bricks to simulate soil overburden.

The chamber and access tunnel were formed around galvanized steel sheet metal, shaped to the required cross-sections (Figures 1 and 2). A layer of mortar approximately 4 cm thick was placed around the top and sides of the chamber form to fill voids between the form and the bricks, and bricks were placed around the assembly. The same procedure was used to form the access tunnel in the model. The chamber was constructed first, and the sheet metal form removed prior to installation of the tunnel section.

INSTRUMENTATION

Two accelerometers were positioned in the overburden above the tunnel/chamber centerline to measure the motions of the cover material for each test. Four internal airblast pressure gages (two in the chamber wall and two in the access tunnel floor) recorded the internal pressure environment. Six free-field pressure gages were permanently installed in front of the tunnel portal, along the extended tunnel/chamber centerline. The gage mounts were cast into a 10-cm thick concrete slab. The concrete slab was 1.8 m wide and extended a distance of 6 m from the tunnel portal. The surface of the pavement was level out to a distance of 1.5 m, where a downward slope (11 degrees) began.

EXPLOSIVE CHARGES

The explosive charges were assembled from 0.085-kg/m (400-grain per foot) PETN detonating cord, cut in 48-cm lengths and inserted through the access tunnel into the chamber. Charge weights, chamber loading densities, and dimensions of the explosive charges are given in Table 1.

EJECTA/DEBRIS COLLECTION

Previous test experiences and analytical studies have clearly shown that, while debris throw ranges and relative distributions can be scaled by model tests, the areal density (impacts per m^2) cannot. This is because the model material which comprises the debris source does not break up with the same size distribution as does the prototype material. Consequently, for Tests 1 and 2, only the maximum range of ejecta/debris was recorded. However, a more detailed ejecta survey was made after Test 3. The locations

of the sample areas are shown in Figure 5. The debris distribution data was broken down into the number of pieces smaller than half of a brick, and those larger than half.

RESULTS AND DISCUSSION

The free-field airblast peak pressure predictions for the brick model are presented in Figure 6. These predictions were developed from the prototype, large-scale Shallow Underground Test, and small-scale concrete model (Norwegian Defence Construction Service) data. The corresponding model (Test 1) data are included for comparison. The distances from the model portal were multiplied by the 1:25 scale factor in this plot to match the prototype scale. As shown here, the brick model data clearly falls within the band spread of the predictions.

In Figure 7, the ratio of calculated exit pressure (i.e., peak airblast pressure at the tunnel portal) to measured free-field (external) overpressure is plotted versus normalized distance from the tunnel portal, for all available data from previous tests of underground magazines. The Brick Model Tests (WES Model (1:25)) are included, along with six other model series and two full-scale tests, including the Shallow Underground Test (KLOTZ (88)). The exit pressures were calculated from the relation given by Vretblad, 1988:

$$P_w = 17.7\ (Q / V_T)^{0.45}$$

where P_w is the exit pressure, bars
Q is the TNT-equivalent explosive weight, kg
and V_T is the total volume of the underground facility, m^3.

A reference line through the data in Figure 7 can be expressed by the equation

$$P_w / P_{so} = 1.0\ (R / D)^{1.35}$$

and $$D = 4\ A / p$$

where P_{so} is the free-field overpressure, bars
R is the horizontal distance from the portal, m
D is the hydraulic diameter of the tunnel (for turbulent flow), m
A is the minimum cross-sectional area of the tunnel, m^2
and p is the perimeter of the minimum cross-sectional area, m

As shown in Figure 7, the data exhibits considerable scatter, with many of the points lying above the reference line. Note however, that the results of the Brick Model

tests and the Shallow Underground Test (solid data points) fall well within the scatter band, near the reference line.

Table 2 lists the Inhabited Building Distances (scaled up to full-scale ranges) derived from five model tests with similar loading densities, but withdifferent scaled cover depths and cover material strengths. There is a clear trend in the effect of the overall integrity of the chamber cover on the IBD. With similar cover thicknesses and loading densities, the heavily-jointed brick model produced about the same long-range blast pressures as did the Norwegian model having a sand cover. Based on the IBD's, however, the Norwegian model having concrete cover material produced a long-range blast pressure equivalent to a heavily-jointed brick model with almost twice the cover thickness.

Measured peak pressures from all three Brick Model tests are plotted in Figure 8. The DDESB airblast prediction equation and the curve fit to the peak overpressure data of the Shallow Underground Test are included in Figure 8 for comparison. Although there is some data scatter, certain trends are indicated. When the cover depth was held constant and the loading density was reduced from 60 to 10 kg/m^3 (Test 2 versus Test 1), the portal pressure was reduced by a factor of about four, and the long-range external pressures were about halved. When the scaled cover depth of the brick models was increased from 0.44 to 0.79 $m/kg^{1/3}$ (Test 3 versus Test 1), and the chamber loading density held constant at 60 kg/m^3, the side-on overpressures outside the tunnel portal increased an average of 30 percent. The peak pressure midway down the access tunnel increased by about 130 percent. When the scaled cover depth was held constant at 0.8 $m/kg^{1/3}$, an increase in chamber loading density from 10 to 60 kg/m^3 (Test 3 versus Test 2) produced an average of 250 percent increase in the free-field side-on overpressure outside the portal.

From Figure 8, it is interesting to note the degree to which the internal and external airblast overpressures measured on the large-scale, Shallow Underground Test were reproduced in the 1:25-scale brick model (Test 1). In general, the model provided a good representation of the prototype results. The tunnel exit pressures match very closely, but external overpressures were low by a factor of approximately three in the free-field. However, these lower pressures may have been due to the downward slope of the ground surface constructed for the model (see Figure 3) at the far-field gage stations.

The peak impulse values from the model tests, obtained by integrating the overpressure-time histories, are plotted versus distance from the charge initiation point in Figure 9. The peak impulse data curve from the Shallow Underground Test are included in Figure 9 for comparison. Although peak impulse shows more scatter than the overpressure data, the model and prototype data clearly follow the same trends.

Figure 10 is a plot of IBDistance (distance to the 5.0 kPa pressure level) versus loading density for selected tests, where the loading density is based on the total volume of the storage facility (i.e., the volume of the chamber plus the access tunnel). A curved line has been drawn through the data points for the WES 1:75-scale model test (Smith, et al, 1989). These small-scale tests were conducted in a model chamber and access tunnel formed with steel pipe and cast in a heavily reinforced concrete block. Therefore, this model represents a totally non-responding magazine structure. The data from the large-scale 1987 KLOTZ test at Alvdalen, Sweden (Vretblad 1988) fall very close to the WES 1:75-scale model curve. The Alvdalen tests were conducted in rock chambers with sufficient overburden to prevent rupture and cover venting, and therefore also represent non-responding structures.

The remaining data presented in Figure 10 are from tests where the overburden ruptured (responding magazines), allowing release of the detonation gas pressures in the storage chamber through the cover venting. The full-scale IBD's derived from the Shallow Underground Test, the Brick Model Tests, and the Norwegian model tests (Jenssen and Krest, 1988) all fall well below the IBD curve for the non-responding magazine tests, by about a factor of four.

While the IBD's for the responding magazines may at first appear unrelated, certain trends are indicated. For example, the Brick Model Tests show an increase in IBD of 25 percent (from 212 to 266 m in full-scale) when the scaled cover thickness was increased from 0.44 to 0.79 $m/kg^{1/3}$. Similarly, increasing the total loading density (mass of explosives divided by total volume of the underground facility) from 7.1 to 42.9 kg/m^3 increased the IBD by 77 percent (from 150 to 266 m), when the scaled cover depth was held constant at about 0.8 $m/kg^{1/3}$.

DEBRIS THROW

The maximum ranges of debris observed on the Brick Model Tests were 91 m for Test 1, and 32 m for Test 3 (Joachim, 92). Using $W^{1/6}$ scaling, the range for Test 1 is less than half the maximum range observed on the large-scale test. On Test 3, the explosive charge was larger than that of Test 2, but the cover thickness was also greater, resulting in the same (or nearly so) scaled cover thickness of 0.8 $m/kg^{1/3}$. All of the debris moved outward from the surface slope over the tunnel and chamber, within a sector extending about 30 degrees to each side of the extended tunnel axis (see Figure 11). The vast majority of debris pieces were fragments less than 1/2 brick in size, indicating that the initial shock shattered most of the bricks near the surface.

Figure 12 shows a series of curves (from Helseth, 1982) relating debris launch velocity to the scaled cover thickness and the magazine loading density. The data sources range from aircraft shelters, which had very shallow cover thicknesses and

loading densities, to buried cratering charges, which had very deep covers and very high loading densities. Underground magazines would typically fall between two extremes.

Dimensional analyses show that the ratio of velocities measured in a model test to those occurring in a full-scale test is equal to the square root of the model scale factor. Therefore, the peak velocity measured by Gage GM-2 in Test 2 of the Brick Model Tests was multiplied by 5, and plotted in Figure 12 along with launch velocities recorded on the large-scale Shallow Underground Test. While this single data point from the Brick Model Tests appear to almost exactly match the curves and other data of Figure 12, it must be remembered that the Gage GM-2 was not at the cover surface, but at mid-depth in the cover. The actual launch velocity for Test 2 (small though it was, as evidenced by the short debris travel) was no doubt somewhat greater than at the gage point.

Also shown in Figure 12 is the launch velocity based on the ballistic calculation for Test 1. The value, which was also multiplied by a velocity scaling factor of 5 for plotting on Figure 12, appears to be somewhat low in comparison to the full-scale Shallow Underground Test.

Figure 13 shows the debris areal density (number of impacts per square metre), as a function of range from the tunnel portal, for Brick Model Test 3 compared to that of the large-scale Shallow Underground Test. In accordance with accepted scaling procedures for ejecta/debris (Rooke, 1980), the distances in the model case have been scaled up by multiplying by the sixth root of the ratio of the model-versus-prototype charge weights, i.e., $(20{,}000\ \mathrm{kg}/1.27\ \mathrm{kg})^{1/6}$.

It is not possible to quantitatively compare the debris densities of the Brick Model Tests with those of the full-scale test, since the number of fragments produced by the cover breakup does not scale. Therefore Figure 13 should be regarded only as a comparison of the <u>relative</u> debris densities recorded on Brick Model Test 3 as a function of range and azimuth, with similar relations from the large-scale test. To provide such a comparison, the entire grouping of the model data has been arbitrarily positioned with respect to the ordinate scale of Figure 13. Considering this limitation, the comparison is actually quite good. the attenuation of the model impact densities with distance closely matches the shape of the curves from the large-scale data. The relative differences between the debris densities along the extended tunnel axis (0-degree azimuth) and the densities "off-axis" also compare quite well with the large-scale results.

CONCLUSIONS

Peak airblast overpressure and impulse values measured on the Brick Model Tests at the tunnel exit and in the near-field (just outside the portal) closely match the results of the corresponding large-scale test. The model pressure data in the far-field was somewhat lower than measured in the large-scale test, possibly due to the gravity and inertial effects resulting from our inability to properly scale the overburden. A comparison among the model test results shows an increase in pressure of a factor of 4 to 6 when the chamber loading density was increased from 10 to 60 kg/m^3. An overpressure increase on the order of 90 percent was seen when the scaled overburden thickness was increased from 0.44 to 0.79 $m/kg^{1/3}$. The Inhabited Building Distance indicated by the model tests was significantly less than for the cooresponding large-scale Shallow Underground Test, but this was also attributed to overburden scaling deficiencies.

Ejecta impact data collected from Brick Model Test 3 demonstrate the feasibility of modeling the basic nature of overburden ejecta throwout. Because the breakup of the cover material does not scale, however, ejecta sizes in the model tests were much too large to accurately define the ejecta hazard range, in terms of impacts-per-square meter.

ACKNOWLEDGEMENT

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REFERENCES

1. Davis, Landon K.; and McAneny, Colin C.; 1981, "Project SPERRE, Report 5, Summary Report: Road Cratering Tests in Rock With Preemplaced Charges," Technical Report SL-81-5, U.S Army Engineer Waterways Experiment Station, Vicksburg, MS.

2. Helseth, Einar S.; "Underground Ammunition Storage, Model test in scale 1:100 in Sand," Fortifikatorisk Notat NR 160/82, Progress Report to KLOTZ Club Meeting, Norfolk, VA.

3. Jenssen, Arnfinn; and Krest, Ottar; 1988, "Shallow Underground Ammunition Magazine Trials at Naval Weapons Center (NWC), China Lake, Ad Hoc Model Tests, Approximate Scale 1:24.8," FORTIFIKATORISK NOTAT NR 192/88, Norwegian Defence Construction Service, Oslo Norway.

4. Joachim, Charles E.; and Smith, Dennis R.; 1988, "WES Underground Magazine Model Test," Twenty Third DOD Explosives Safety Seminar, Atlanta, GA.

5. Joachim, Charles E.; 1990, "Shallow Underground Tunnel/Chamber Explosion Test Program, Summary Report," Technical Report SL-90-10, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

6. Joachim, Charles E.; 1992, "Brick Model Tests of Shallow Underground Magazines," Miscellaneous Paper SL-92-2, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

7. Millington, Charles, 1985, "The Ernestettle Report," Preliminary AWRE Report UK(ST)IWP 205, O/1/85, AWRE (Foulness), Ministry of Defence, United Kingdom.

8. Rooke, Allen D., Jr., 1980, "Crater-Ejecta Hazard Predictions in Cohesive Soils, The Middle Gust 1 Event," Thesis, Master of Science, Mississippi State University, Mississippi State, MS.

9. Smith, Dennis R.; Joachim, Charles E.; Davis, Landon K.; and McMahon, Gordon W.; 1989, "Effects of Explosions in Underground Magazines," Technical Report SL-89-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

10. Stromsoe, E.; 1969, "Underground Explosion Trials at Raufoss 1969, Measurement of Airblast Outside The Tunnel," Intern Rapport X-124, FORSVARETS FORSKNINGSINSTITUTT, Norwegian Defence Research Establishment, Kjeller, Norway.

11. Vretblad, Bengt; 1988, "Data from the 1987 KLOTZ Club Tests In Sweden, Report C3:88, FORTIFIKATIONSFORVALTNINGEN, FORSKNINGSBYRAN, Eskiltuna, Sweden.

Table 1. WES Brick Model Tests: Explosives Charges, and Chamber Cover Thicknesses							
	Explosive Charge					Minimum Scaled	
Test No.	Total Mass (kg)	Loading* Density (kg/m^3)	No. of** Strands	Length (cm)	Diameter (cm)	Chamber Cover ($m/kg^{1/3}$)	Portal Cover ($m/kg^{1/3}$)
1	1.27	60	31	48	5	0.44	0.034
2	0.21	10	5	48		0.80	0.062
3	1.27	60	31	48	5	0.79	0.49

* Mass of explosives divided by chamber volume.

** 0.085 kg/m (400 grains/foot) detonation cord

Table 2. Effects of Magazine Cover Resistance on Airblast						
					Airblast Effects	
Model Test	Model Scale	Cover Type	Scaled Cover Depth $m/kg^{1/3}$	Loading Density $m,kg^{1/3}$	Portal Pressure MPa	Full-scale IBD m
NDCS Sand	1:24.8	Sand	0.33	58.3	6.2	208
Brick Model 1	1:25	Bricks	0.44	60	5.0	205
NDCS Concrete	1:24.8	Concrete	0.33	58.3	103	250
Brick Model 3	1:25	Bricks	0.79	60	5.0	250
WES Concrete	1:75	Concrete	>2.0	60*	-	1000

* Extrapolated from Figure 12.

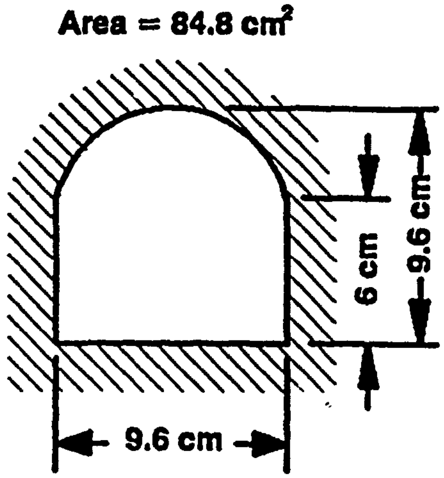

Figure 1. Access tunnel cross-section for 1:25-scale WES Brick Model Tests

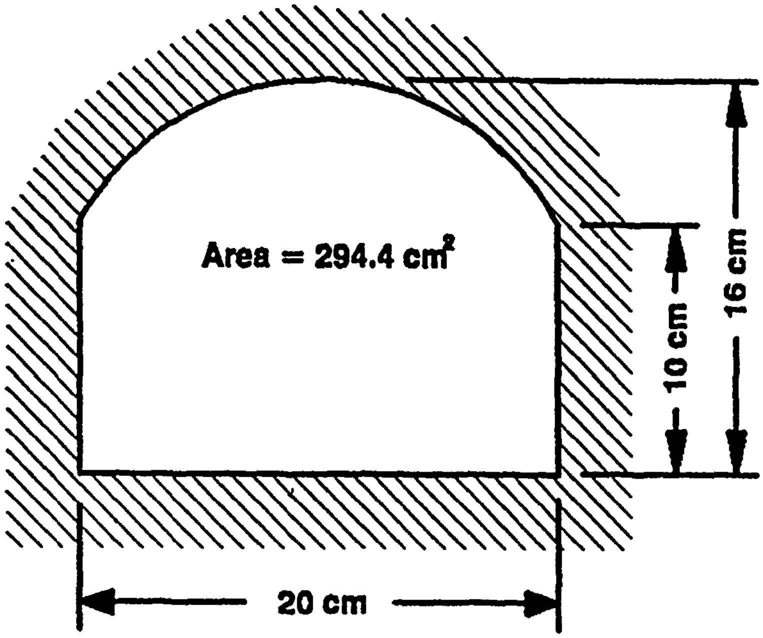

Figure 2. Storage chamber cross-section for 1:25-scale WES Brick Model Tests.

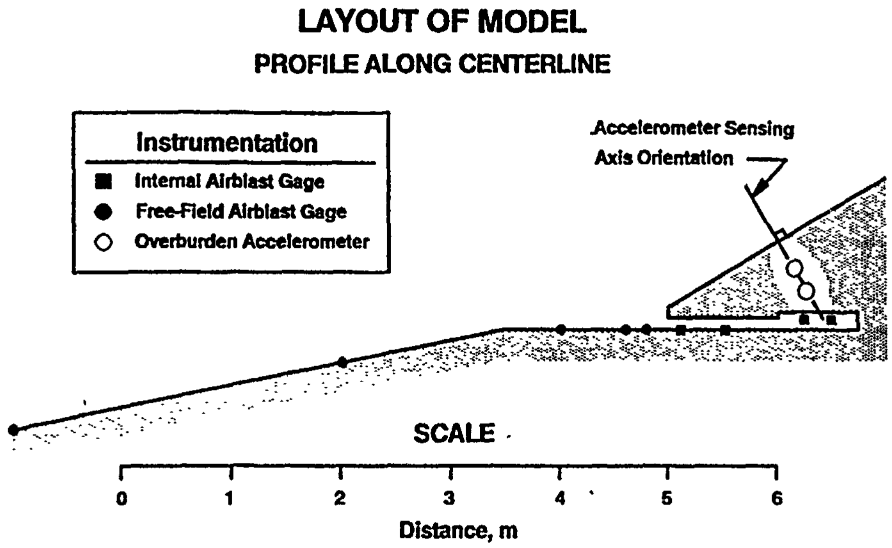

Figure 3. Layout (centerline profile) of 1:25-scale WES Brick Model.

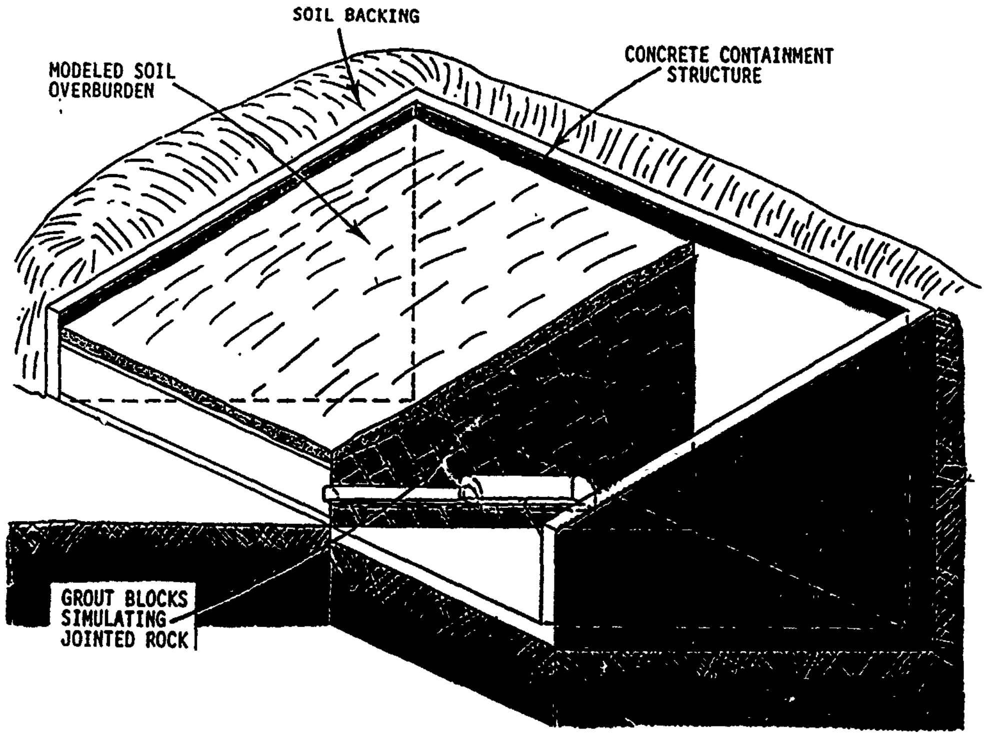

Figure 4. Testbed design for 1:25-scale tests of influence of cover rock characteristics on venting, ejecta, and internal/external airblast levels for shallow underground magazines.

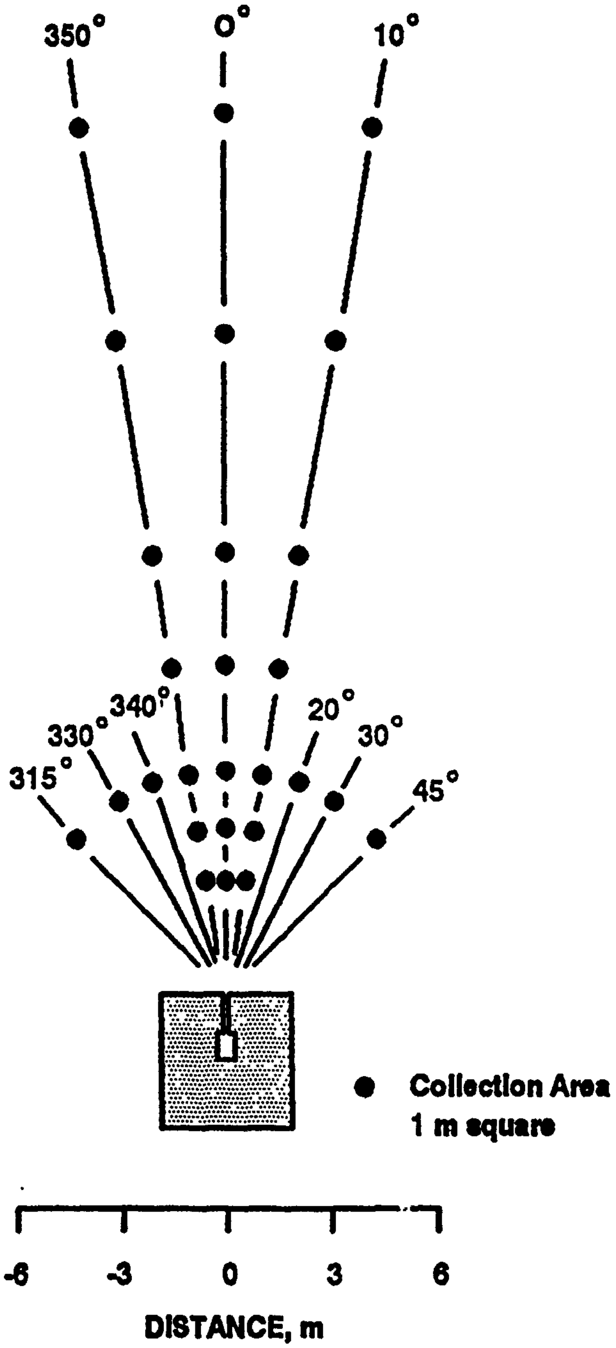

Figure 5. WES Brick Model Test 3: location of ejecta collection areas.

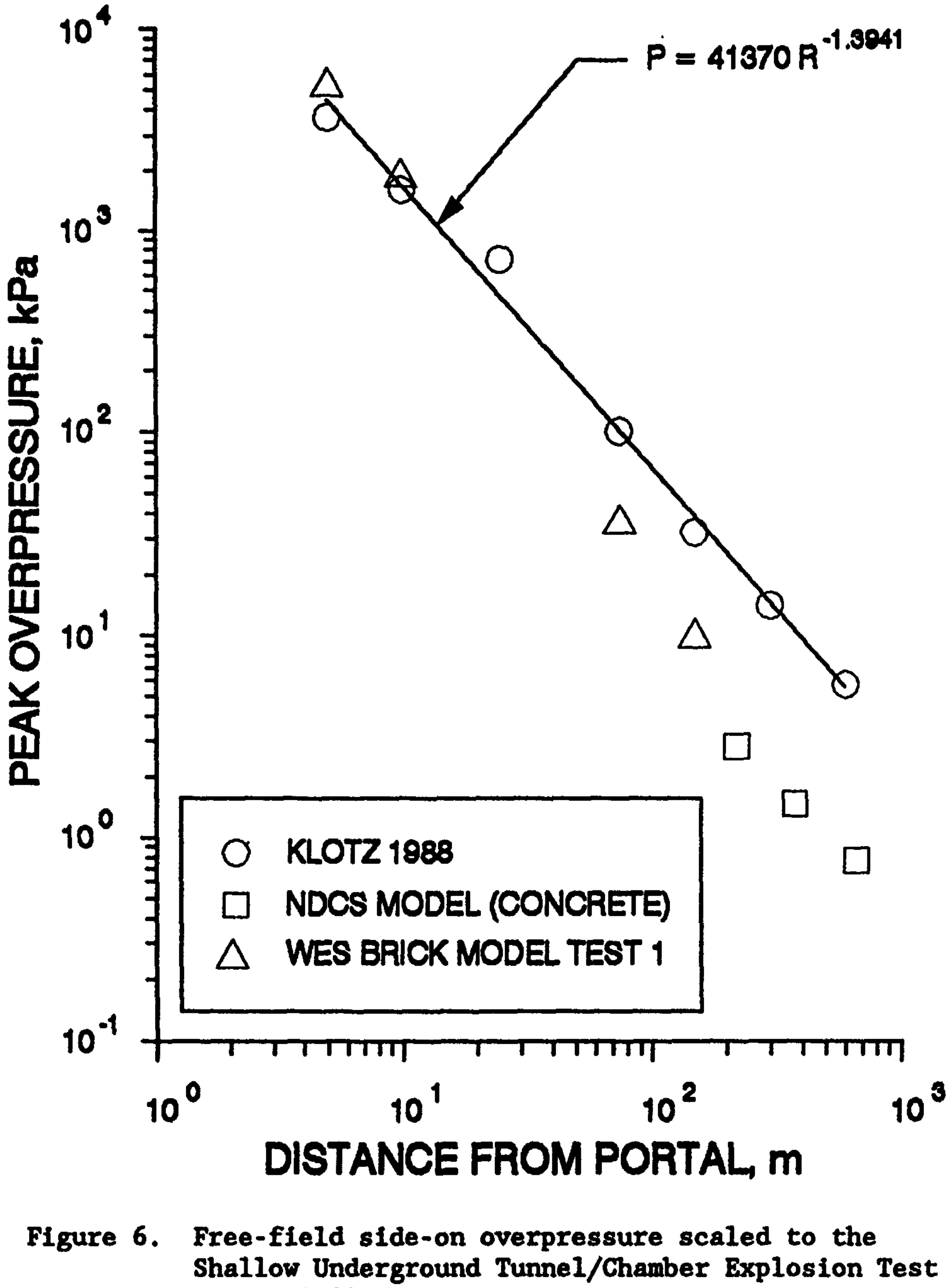

Figure 6. Free-field side-on overpressure scaled to the Shallow Underground Tunnel/Chamber Explosion Test (KLOTZ 1988) parameters.

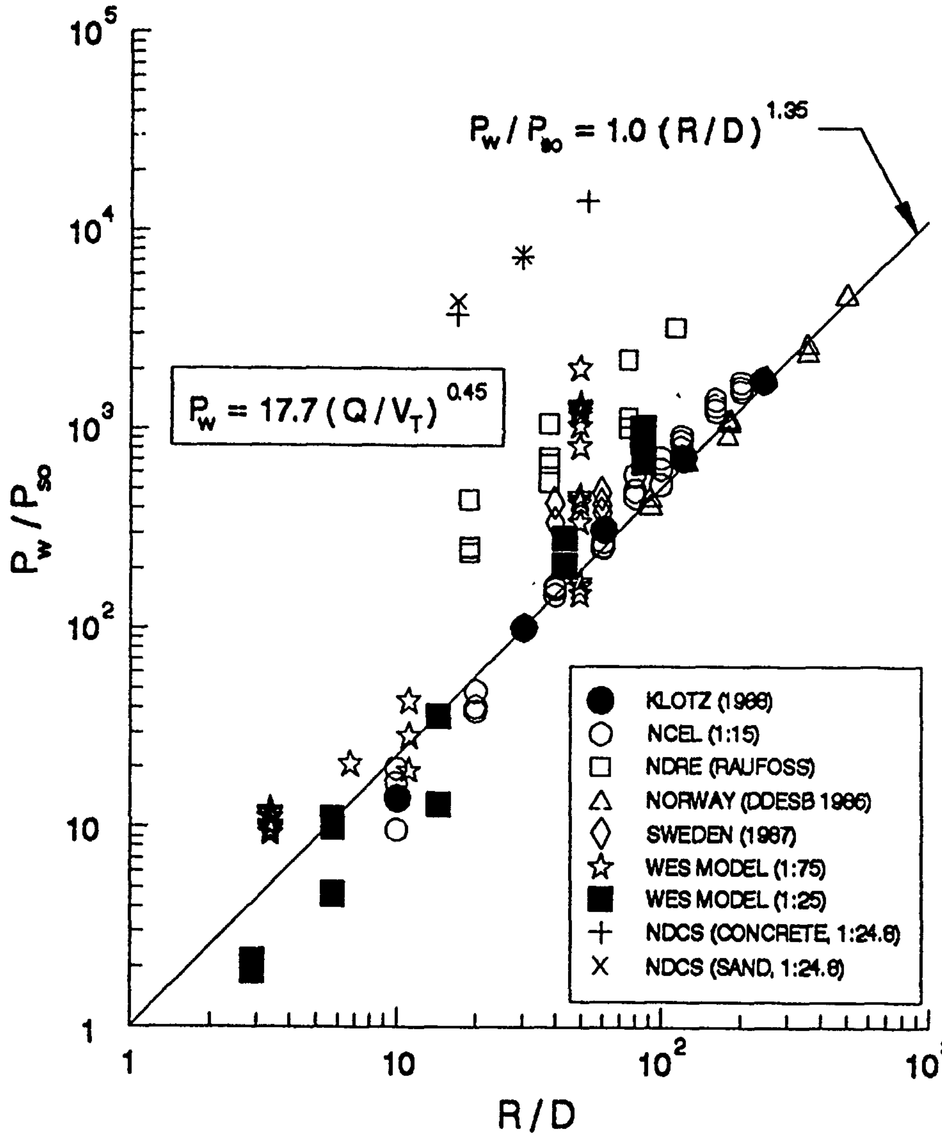

Figure 7. Pressure-distance comparisons from existing data on model and large-scale detonations in underground magazines. The ratio of calculated exit pressure (P_w) to measured free-field side-on overpressure (P_{so}) is plotted versus distance (R) from the tunnel portal along the tunnel/chamber centerline. The distance is normalized by dividing by the hydraulic diameter (for turbilent flow) of the access tunnel cross-section

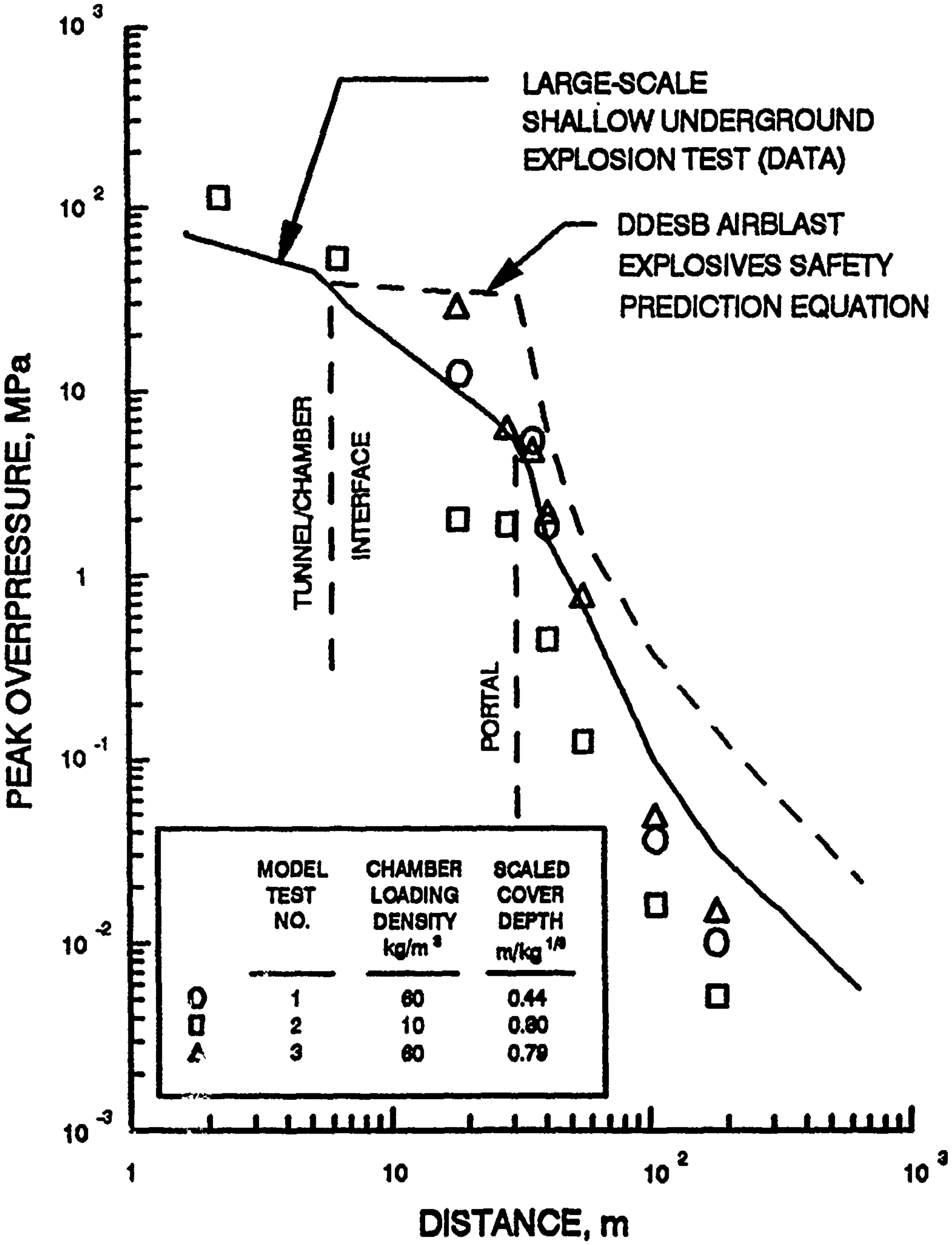

Figure 8. Peak side-on overpressure versus distance from the charge initiation point. A comparison is shown between the prototype (Shallow Underground Tunnel/Chamber Explosion Test, loading density 60 kg/m^3) and the WES Brisk Model Test data.

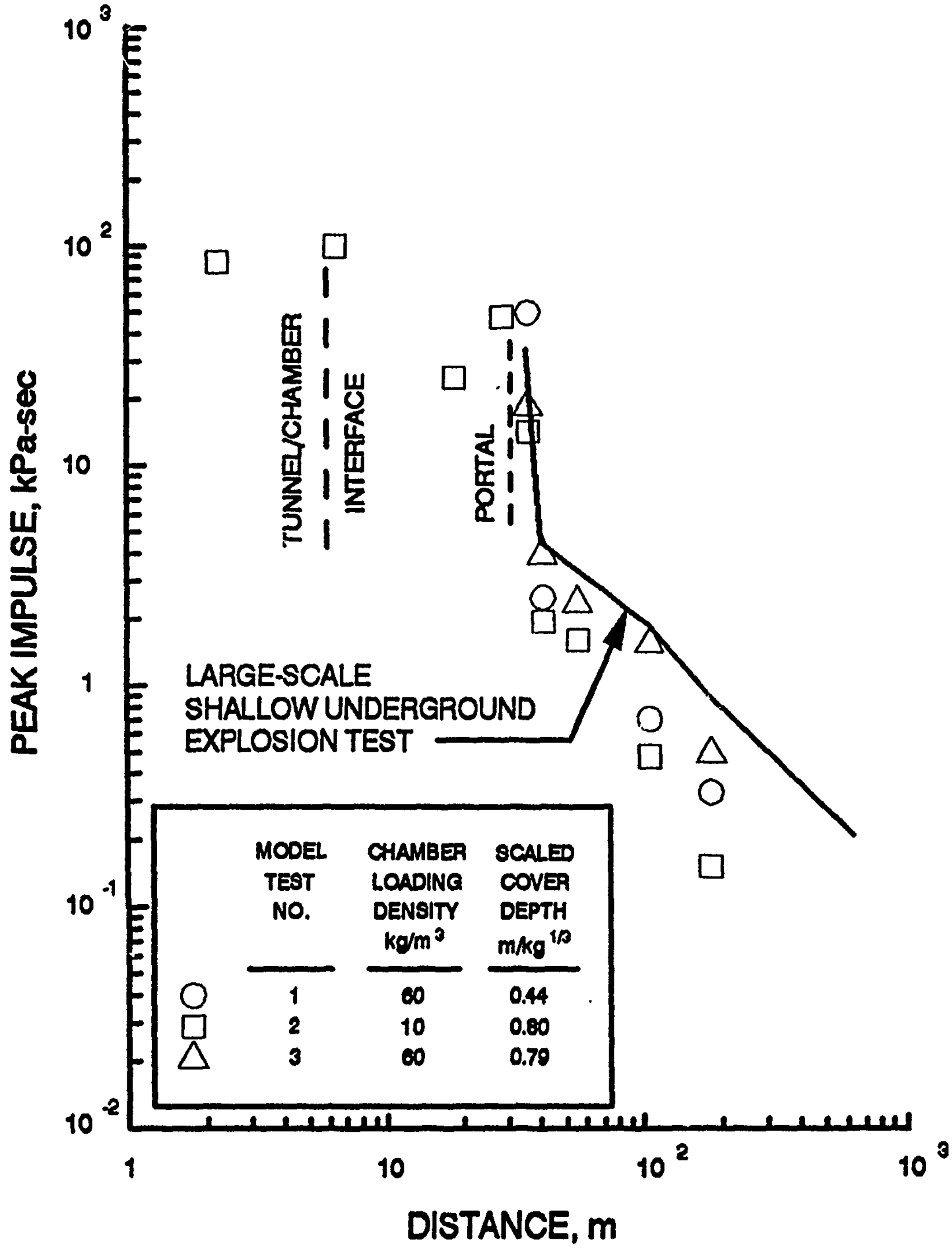

Figure 9. Peak side-on impulse versus distance from the charge initiation point. A comparison is shown between the prototype (Shallow Underground Tunnel/Chamber Explosion Test, loading density 60 kg/m³) and the WES Brisk Model Test data.

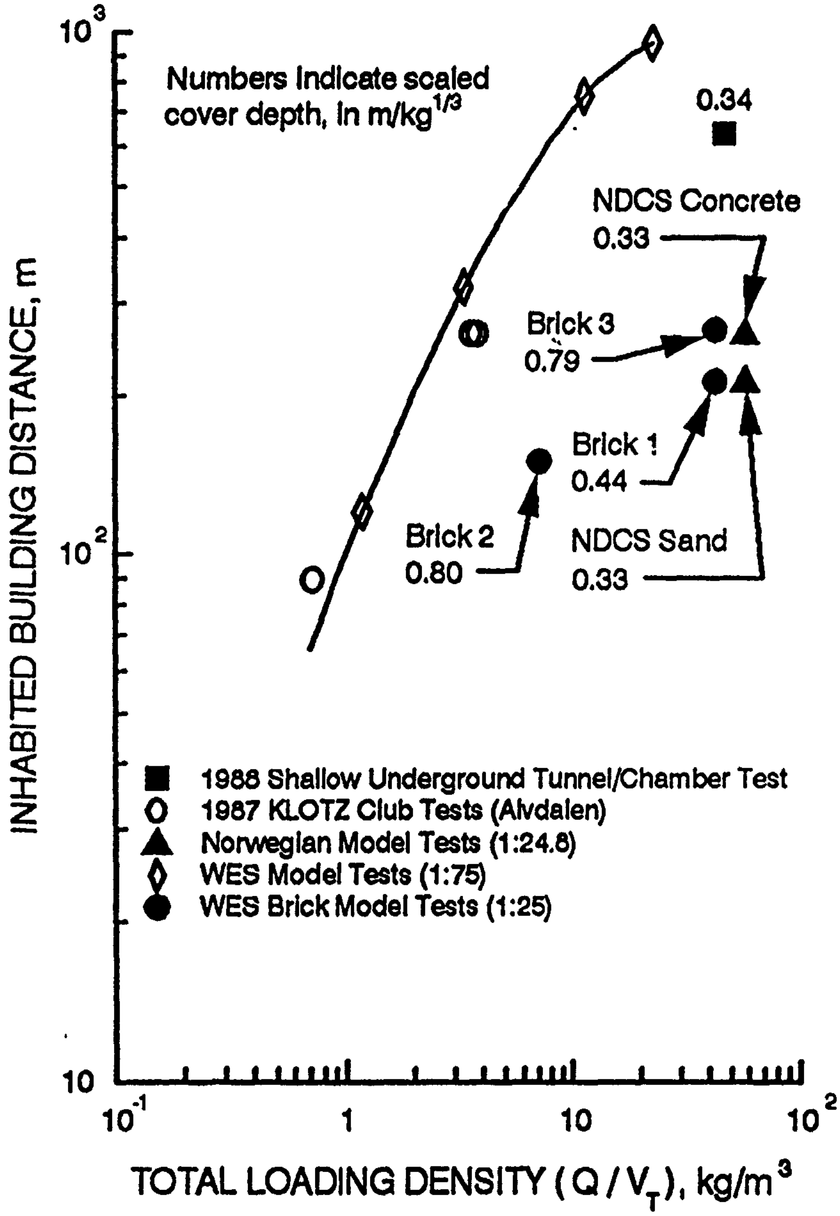

Figure 10. Airblast Inhabited Building Distance versus total loading density (charge mass divided by total internal volume) for selected model and large-scale tests. Solid symbols are for "responding" magazines, and open symbols for "non-responding" magazines.

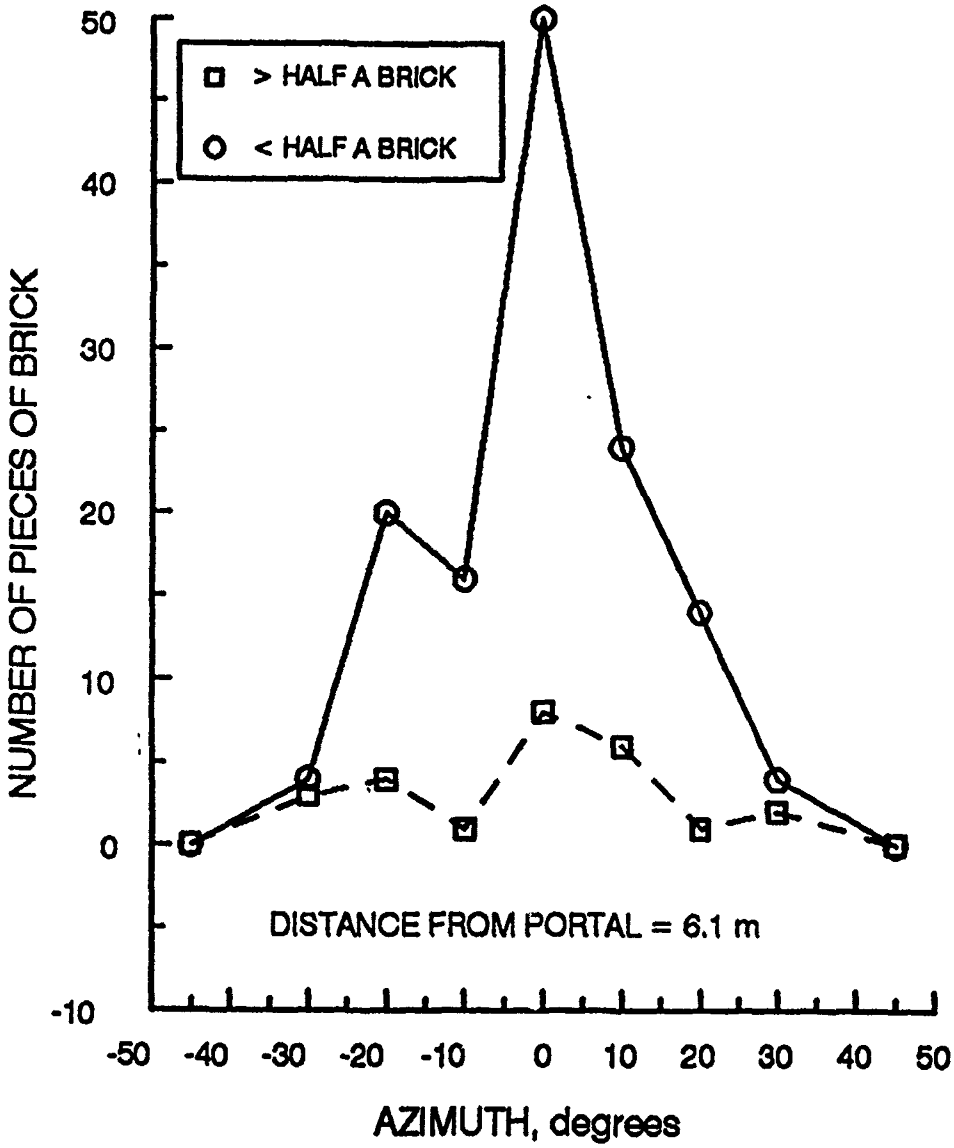

Figure 11. Ejecta distribution as a function of azimuth along the 6.1 m arc, WES Brick Model Test 3.

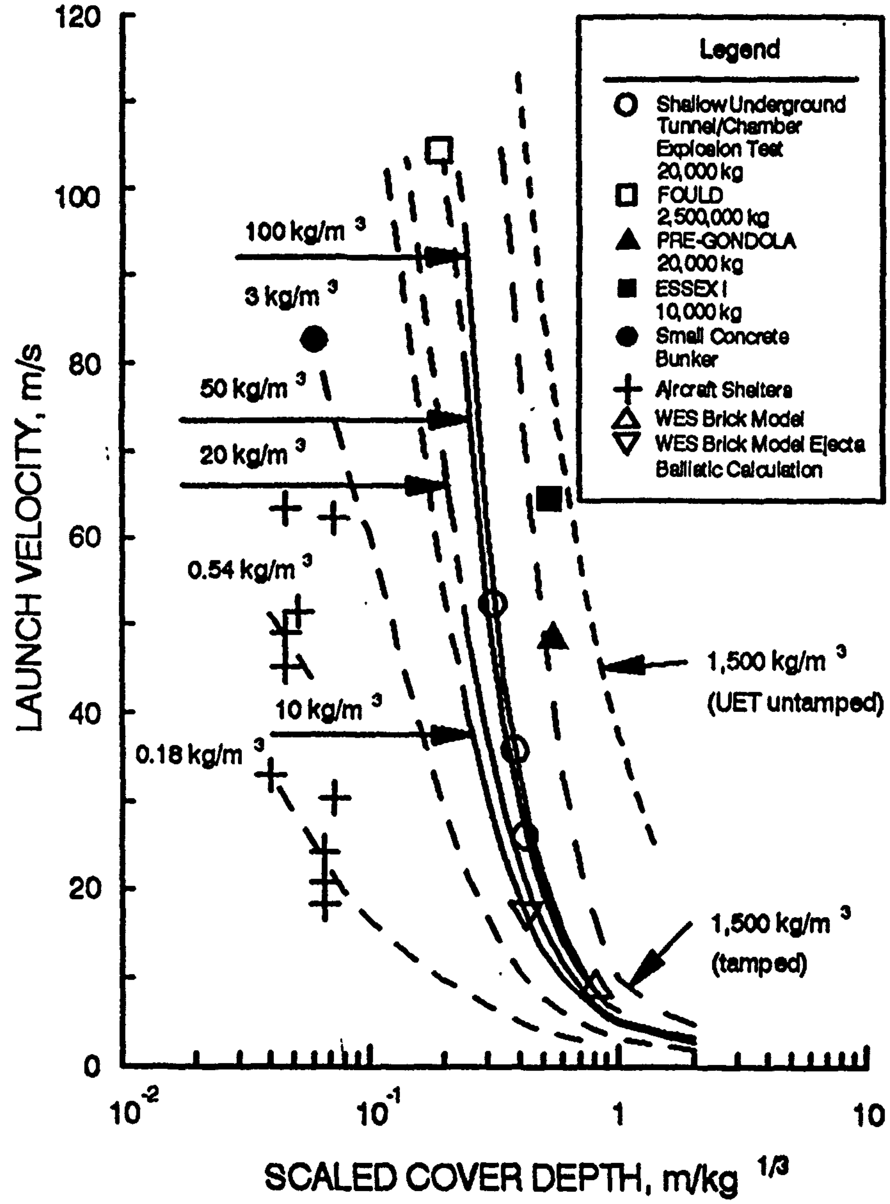

Figure 12. Launch velocity of cover rock ejecta from WES brick model test, compared to ejecta velocities from Shallow Underground Tunnel/Chamber Explosion Test (Joachim, 1990) and other sources (Helseth, 1982) on previous explosion tests.

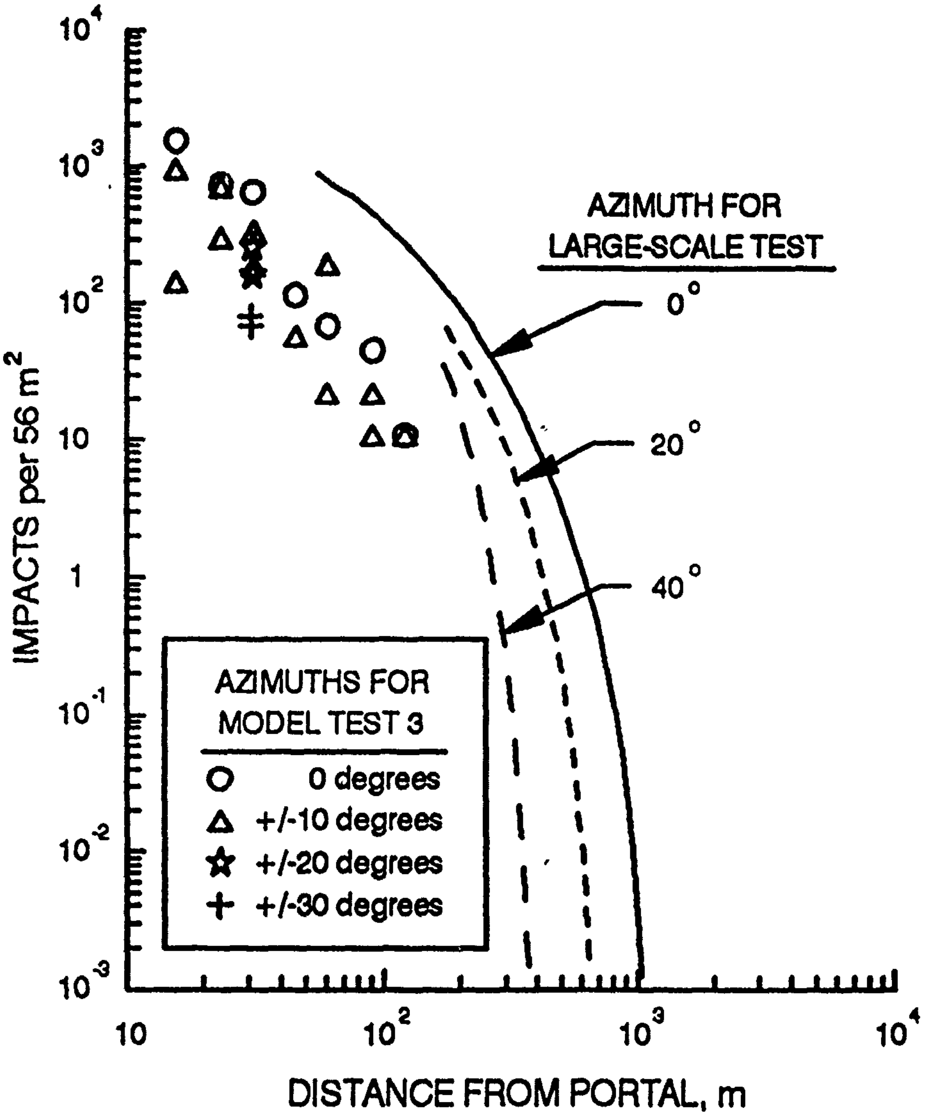

Figure 13. **Relative comparison of debris densities from WES Brick Model Test 3 with Shallow Underground Tunnel/Chamber Explosion Test (KLOTZ 1988) data curves. Distances in the model were scaled by the ratio of the charge weights taken to the one-sixth power.**

FMV:Amsäk
Bo Demin, Chief Engineer 2 January 1992

Measures proposed to improve the safety of materiel within the defence establishment

1. Introduction

In compliance with relevant laws (e.g. the Work Environment Act and a number of special laws, such as those relating to inflammable and explosive goods, the transport of dangerous goods, and safety on board ships), various National Defence authorities are responsible, for the safety of materiel and for preventing accidents both in times of peace and war.

In conjunction with the changes now taking place in both the community and the defence establishment that affect this safety work (such as the European Economic Co-operation Agreement, closer relations with the EC, a new law concerning products, Business Concept -90 and the FMV-90 organization) an complete review should be made and co-ordination carried out to improve this work.

The object of this article is to shed light on the areas involving the most acute problems and, if possible, propose remedies.

2. Distribution of responsibility

Responsibility for the safety of materiel, which is shared among the central authorities, such as the Supreme Commander of the Armed Forces, Commanders-in-Chief of the Army, Navy and Air Force, and the Swedish Defence Material Administration (FMV), needs to be made clear, for reasons that include the responsibilities of the authorities during the various phases of the materiel's service life.

The present distribution of responsibility in accordance with the government's defence activities ordinance is not in accord with relevant legislation.

Furthermore, the distribution of responsibility among central, regional and local authorities must be regulated to take into account Business Concept '90 and other considerations.

Finally, responsibility within FMV must be regulated, with regard to the FMV-90 organization (for example, what safety work implies for a person responsible for materiel systems).

In distributing responsibility, efforts should be made to achieve the greatest possible co-ordination between the defence services, such as in the matter of airworthiness approval, seaworthiness approval, safety approval of other defence materiel, and decisions on the use of the materiel. Another important co-ordination matter is work on Safety Instructions, its formulation, distribution and follow-up, and the further development of this work.

3. System safety activity on all defence materiel

Modern defence materiel is becoming ever more technically complicated, in the form of systems in which electronics and software are already used in applications that are critical to safety.

Systematic safety work must be carried out to meet the requirements on safety examination as regards airworthiness, seaworthiness or other safety approval.

Within the American defence authorities this activity is regulated in accordance with MIL-STD 882B 'System Safety Program Requirements'. Basically, this technique implies:

- that safety is considered as one product quality among others, which can be specified and verified,

- that general constructive requirements to reduce risks are compiled in manuals, standards, etc.,

- that systematic methods are used to survey accident risks and assess the need for measures to reduce risks, and

- that a formal, object-related system safety plan necessitates special reporting of plans for and the results of activities that affect safety.

This technique is today fully applied in the development of JAS39 Gripen and the development of ammunition.

To satisfy the requirement on safety it should be applied to all defence materiel to the necessary extent.

Demands should therefore be made on the execution of system safety work on all defence materiel.

To facilitate the introduction of this activity, a system safety manual should be produced.

4. Electronics and software in applications critical to safety

These applications are becoming increasingly common, such as in the control system for JAS39 Gripen, computer system in the coastal corvettes and submarines, computer systems in robots, torpedoes, etc.

From a safety point of view, this problem area is at present the most difficult one to analyse.

Extensive international study and development work has been carried out to formulate requirements and methods of examination within this field to better enable evaluation of the safety of the system.

Within FMV, this activity should be co-ordinated and regulated as soon as possible, with the necessary service instructions, detailed instructions and personnel examination resources.

5. Resources in companies doing development work

To be able to apply this system-safety technique to the full, companies doing development work require the necessary resources. These resources must meet requirements on examination of details, e.g. of an ignition system, but also examination of a whole system, such as a coastal corvette, a combat vehicle, a complete robot system, with reconnaissance and fire-control radar and the actual robot itself. This implies requirements on the resources of shipyards, the combat-vehicle industry, etc.

Furthermore, this activity must be worked into the rules for development that exist in each company (e.g. in a product production manual).

6. Inflammable and explosive goods

As a result of the new law relating to inflammable and explosive goods, the National Inspectorate of Explosives and Flammables must revise its directives. FMV must participate and guard special defence interests in this work. As a result of this, IFTEX (Instructions for the transport and storage of explosives) and BVKF (The defence establishment's joint regulations for actions against the risk of fire and explosion, water contamination and chemical effects on health by inflammable goods etc.) must be revised, in which the instructions issued by the Cabinet Office concerning the formulation of the instructions must be taken into account.

These instructions affect other corresponding instructions at FMV, such as the new Weapons and ammunitions safety manual and Rules for surveying ammunitions.

The development of Insensitive Munition (IM) (known in Sweden as low-sensitivity ammunition - LKA) is being carried out to impart to materials containing gunpowder or explosives greater peacetime and, above all, greater wartime operative safety.

The introduction of such ammunition is of decisive importance for the survival of weapons-carriers (e.g. Combat vehicle 90, new tanks, JAS39 Gripen, new surface attack vessels, new submarines), the Supreme Commander should as soon as possible issue a policy document concerning the stipulation of requirements on new ammunition and the modification of existing ammunition.

To be better able to examine the safety (and performance) of the explosives that are to be used, explosives for military purposes should be subjected to qualification.

7. Weapons-environment work and testing

Basically, safety may be verified in two ways:

- theoretically, by means of analyses, and
- practically, by testing.

Testing includes checking that materiel will be able to withstand the environment they will be exposed to in their service life.

The more complicated the material and the more electronics it contains, the more important it is that weapons-environment work be carried out in a correct manner.

This activity should be better managed and co-ordinated at FMV.

The testing directorate should be given responsibility for:

- advising project leaders on weapons-environment work
- preparing and co-ordinating norms (standards) in this field, and
- co-ordinating test equipment, both within FMV and between FMV and the defence industry and other testing organizations, such as the Swedish National Testing Institute (SP), the National Defence Research Institute (FOA) and certain universities and colleges of higher learning.

8. Rules for following-up the safety status of materiel

Materiel must be continually followed up to ensure that it satisfies the safety (and performance) requirements that its object places on them.

In the field of ammunition, this activity is controlled by the 'FMV rules for ammunition surveillance', which stipulates general requirements on the activity, including the requirement that in the development of ammunition, a plan for following it up shall be prepared and contain safety (and performance) criteria.

In a corresponding way, to the extent that it does not already exist, controlling general regulations should be prepared for other fields (e.g. weapons), stipulating the general rules governing this activity.

9. The new Product Responsibility Act

As from 1 January 1993, a new Product Responsibility Act is to be introduced in Sweden which is in broad agreement with EC product responsibility directives.

Basically this law implies that companies that develop products shall, for the first 10 years, bear responsibility in the event of the product causing injury/damage as a result of a fault in design or production.

This makes demands on industries that do product (system) safety work.

Here, the way in which the responsibility and safety work is to be shared between FMV and industry must be regulated. This issue affects main agreements and order contracts for both development and modification work. Furthermore, it affects FMV's way of working with industry, such as in the amount of 'detailed control'.

Other issues are the extent to which FMV workshops have the necessary resources for analysis etc. and what happens after the statutory limitation time has expired.

10. Safety Instructions work

As of 1 October 1991, the Commander-in-Chief of the Army has appointed a safety inspector to achieve better control of Safety Instructions work and, above all, to gain greater understanding for the instructions and apply them better.

To be able to achieve a better balance within Safety Instructions systems, this inspector should bear total responsibility for co-ordination and not only responsibility for the parts of Safety Instructions for which the Army Staff is today responsible. This applies to design co-ordination, distribution, revision cycle, etc.

Furthermore, it is intended in the army's field to work the technical parts of Ammunition clearance into the Safety Instructions. Corresponding adjustments should be made in the other armed services.

In the short term, relevant calculation bases for factors in the Safety Instructions that affect safety, such as k, V, U, Q, noise, pressure, etc., should be cleared up.

The distribution of responsibility in carrying out follow-up work at FMV and the methods employed at it must be examined.

In the long term, follow-up should be carried out on the present 'philosophical' studies of Safety Instructions being made in Australia and within NATO (Supreme Commander) that are intended to result in

- the 'user' specifying a desirable risk level in the intended training case,

- meeting this requirement by determining real risk criteria for various types of risk and using a suitable mathematical model to adapt them to data processing.

11. Consequences of the European Economic Co-operation Agreement and closer ties with the EC

The implications of the European Economic Co-operation Agreement include the requirement that Sweden follow EC directives such as the Machine directive. In verifying safety (testing), European standards shall also be applied.

Here, a review must be made quickly of the directives and standards that must be followed and a policy prepared to indicate how these shall be applied to defence materiel.

In this context, the work being done within NATO and on the co-ordination of the European defence industry must be followed up.

12. Orientation of research in this field

The US Critical Technologies Plan (CTP), contains several technologies that affect safety work which are not contained in the Swedish research orientation, for example:

- semi-conductor materials and micro-electronic circuits

- software producibility

- weapon system environment

- high-density materials (e.g. IM application)

It is worth considering whether or not to orient Swedish research towards these fields as well.

Furthermore, research and development should be aimed at new methods of analysis as a compliment to FTA and FMEA, specially to obtain a quick idea of where parts critical to safety are located in large systems, which require more careful analyses.

13. Summary

Efforts should be made to obtain a co-ordinated grip of the activities being carried out to improve the safety of materiel in defence establishment systems.

Briefly, this implies:

- that matters of responsibility be surveyed,
- that demands be made on the system-safety activities for all defence materiel,
- that demands be made on electronics and software in applications critical to safety,
- that companies be given the necessary resources for these activities,
- that safety concerning inflammable and explosive goods be improved by revising IFTEX and BVKF, by introducing requirements on IM and by the qualification of explosives intended for military purposes,
- that the methodology and responsibility for weapons-environment work be regulated within FMV,
- that follow-up of the safety status of materiel be controlled in conjunction with its procurement,
- that the consequences of the new Product Responsibility Act as regards defence materiel be investigated and an FMV policy on this matter be determined,
- that Safety Instructions work be co-ordinated between the defence services and that a short-term and long-term policy for this work be determined,
- that the consequences related to the European Economic Co-operation Agreement and closer ties with the EC be studied as regards the directives that must be followed and the standards and norms that are to be applied, and
- that the necessary research and development be planned and carried out in this field of activity.

Twenty-fifth Explosives Safety Seminar

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STORAGE COST - BENEFIT ANALYSIS IN CASE OF GIVING UP 1.1 MUNITIONS

by Jean GOLIGER *, Laurent ALLAIN *, Jean ISLER *
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FRANCE

ABSTRACT

Life Cycle Cost of Ammunition includes acquisition cost, storage cost, maintenance and elimination costs, and accident cost as well.

This paper analyses what could be, during the ground storage step, the financial gain with facilities, in case of renunciation to 1.1 munitions. According to UN and Nato definitions, 1.1 munitions present a mass explosion hazard. Other than 1.1 munitions are 1.2, 1.3, 1.4 or 1.6 munitions. Such munitions present a projection and/or a fire hazard but no more a mass explosion hazard. As soon as they are no more relevant of Class Division 1.1, a gain in storage facilities (buildings and required areas) can be obtained. If 1.1 munitions were given up, the extra cost of acquisition of less sensitive ammunition could be in some part supported by gains on facilities. Igloo type buildings might be replaced by lighter magazines, cheaper to build. Isolation distances would be reduced and allow to gain area. Economical analysis is presented and the possibilities of a new "non 1.1 magazine" is also debated.

CONTENTS

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INTRODUCTION

Procurement to Armed forces of munitions, less sensitive than existing ones, may apparently require some extracost in order to develop them and put them in service. However it is interesting for Armed Forces to consider not only the acquisition cost, but also the storage cost, the maintenance and elimination costs, and accident cost as well. All these cost elements are included in what is usually called the Life Cycle Cost (LCC).

As safety and vulnerability are the major constraints for ammunition facilities, Less Sensitive Munitions (LSM) with comparable performance, present reduced operations and support costs.

Life Cycle costing is a complex and delicate work.

A first guide for Life Cycle costing is (ref. 1) the "Life Cycle Cost Model for Defense materiel systems". This US handbook provides comparable cost structures and methods for all major types of materiel systems, including ammunition, for the US Marine Corps.

In this model, operations are limited to peace time including training operations.

The pilot NIMIC (Nato Insensitive Munitions Center) has produced (ref. 2) an interesting analysis of cost-benefit of Insensitive Munitions. This paper considers both peace and war times.

A reliable comparison of Life Cycle Cost of LSM versus usual munitions, would be an important work to do. It cannot be done by industry alone.

On the other hand, storage facilities are well defined and familiar to industry.

Storage cost elements can be picked up and bound together for a comparison. Specially for aboveground facilities which are dealt by many hand books.

So, in this paper, we will focus on economical gains for aboveground storage facilities and more narrowly on earth-covered magazines, by using LSM.

We will use, as our main reference, during this analysis, the NATO AC 258-D258 Manual for Storage of Ammunition and Explosives (ref. 3).

We will make no assumption on crisis or war times, except the fact that in such a period, intentional stimuli are possible and some additional protection needs to be considered. We assume that LSM have comparable efficiency to that of usual munitions.

We will focus on a specific, but perhaps most dramatic, evolution during next years, i.e. the fact that non mass-exploding ammunition replacing existing 1.1 munitions will arrive on the market and in Forces. They will be 1.2, 1.3, 1.4 or 1.6.

In this paper so, we will try to elucidate economical gain for aboveground storage facilities in earth covered magazines in the situation where 1.1 ammunition would be given up. We will point out the need to adapt facilities to LSM, and the possibilities of using lighter standard magazines.

FIRST PART - NON MASS-EXPLODING MUNITIONS

Existing munitions can be divided in two groups :

- mass - exploding munitions

which are classified 1.1 according to UN and NATO definitions;

- non mass-exploding munitions

which are classified 1.2, 1.3, 1.4 or 1.6 (1.5 is devoted to commercial blasting agents).

1.1 classification is obtained through a mass-explosion at the stack test and/or a mass-explosion at the bonfire according to UN and NATO protocols.
1.1 classification is also imposed, in US, on rocket motors the solid propellant of which is exceeding 70 cards at the US gap test or is blasting cap sensitive.

From an overview of classification results, 1.1 munitions are mainly :

- projectiles above 5 inches,
- some missiles,
- bombs.

On the same way, examples of other than 1.1 munitions are

- fixed ammunition : 20mm, 30mm, 40mm, 76mm, 3"50 (1.2),
- small arms ammunition (1.4).

As long as mass-exploding and non mass-exploding items will coexist in Defense Services, all logistic constraints will be designed and maintained to protect life and property from the major hazard : mass-explosion.

Different NATO countries and companies, among which France and SNPE, are developing substances and munitions less sensitive that present ones, through Insensitive Munition (IM) and 1.6 items programs. Non detonation at Fast Cook Off (FCO) and Sympathetic Detonation (SD) are common requirements.

Munitions which do not detonate at FCO and SD are classified 1.2 or still less severely.

When non mass-exploding items are stored, transported and used, logistic constraints can be immediately dramatically reduced - and benefit is very ominous.

We have however two reservations to do.

Firstly, such a situation with complete disappearance of 1.1 munitions, is not for an immediate future. Huge quantities of large caliber projectiles and bombs are in storage, with expected lifetime of several tens of years. Some renunciation to 1.1 munitions might be however observed.

The second reservation is that non mass-exploding is not equivalent to no-risk.

Residual risks remain. According to classification, they are :

1.2 = fragments, projected munitions, projected unreacted material which can react at the fall out, limited blast, thermal effect.

1.3 = thermal hazard, minor blast, firebrands,

1.4 = effect limited to vicinity of packages,

1.6 = only unitary risk might be considered; thermal hazard.

Major Residual risks will be mainly :

a) unitary risk;
b) projections, either fragments, or projected items, with unreacted items at the fall-out, firebrands, self propulsion items;
c) mass fire.

If one large caliber munition detonates (for example after a shaped charge attack) nearby munitions will be projected at a certain velocity. With a 10 inches bomb, for example, a nearby bomb, may be projected at speed up to 60 meters/second.

Nevertheless, some residual risks will be further significantly reduced as well through emerging technologies. It's not the scope of this paper to remind them.

SECOND PART - TECHNICAL ELEMENTS

Let us consider an aboveground igloo storage consisting of 60 tonnes magazines.

Let us try to identify the possible logistics gain by giving up 1.1 munitions.

Possible reduction of cost depends on reduction of QD and on lighter magazines - for new facilities. For existing facilities, gain depends only on reduction of QD.

2.1. Gains on area

Let us assume that real estate limits go to Public Traffic Route (PTR) and Inhabited Building (IBD) (which are basically the same).

Let us assume 60 tonnes Igloos (8m x 25m available surface)
Let us assume three cases :

1 isolated igloo (case A)
10 igloos (2 x 5) (case B)
100 igloos (10 x 10) (case C)

In cases B and C distance from front to rear is 32m, and there is 20m between lateral walls of igloos.
Distances to PTR and IBD from each igloo are :

1.1 = 22 $Q^{1/3}$ (Nato D 13) ----> 870m
1.2 = 68 $Q^{0.18}$ (Nato D 2) ----> 500m
1.3 = 6.4 $Q^{1/3}$ (Nato D 4) ----> 250m

We observe that 1.3 distance are included in 1.2 distances up to 250 T at least.

As soon as non 1.1 munitions allow to lower QD, some areas are thawed, and gained areas can be observed by drawing two lines for 60 tonnes of 1.1 and 1.2.

In figure 1 hereafter, we present the two lines for case B (10 igloos).

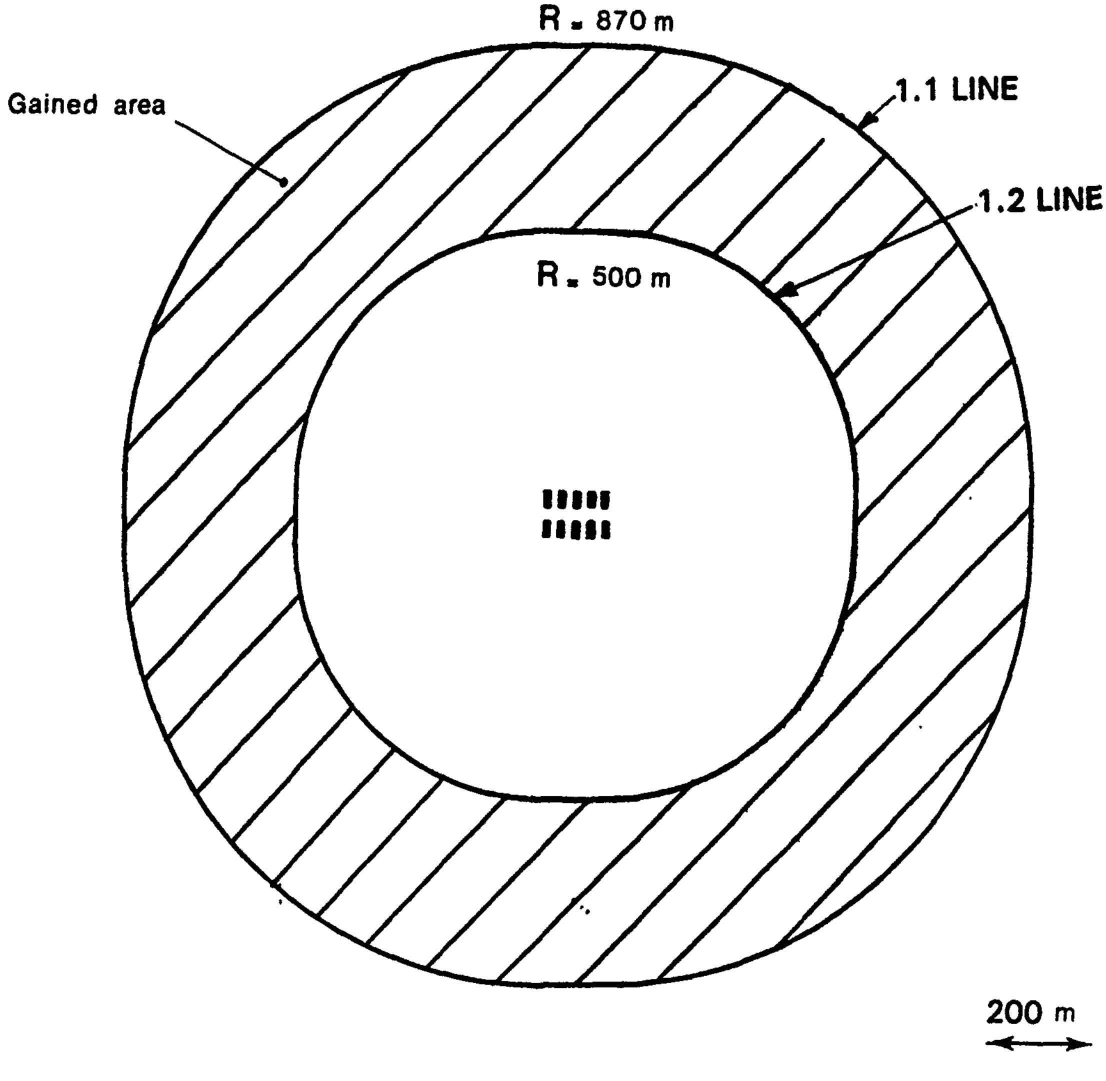

Figure 1 : QD lines and gained area for 10 igloos

Gained areas in the three cases (total and per kilogram of explosive) are presented in table 2 hereafter. Buildings, igloos are supposed unchanged.

	gained area (total)		gained area/kg	
	millions square meters	acres ($4047 m^2$)	m^2/kg	square feet /kg
A 1 single igloo 60 000 kg NEW	1.6	395	27	290
B 10 igloos 600 000 kg NEW	1.8	447	3.0	33
C 100 igloos 6 000 000 kg NEW	2.2	543	0.37	4

Table 2 : Gained areas

2.2. Lighter magazines

Munitions cannot be stored in the open air, and we have to think to new types of magazine, having similar functions to what existing 1.1 igloos offer, but for other Class-Division munitions.

Main functions of an igloo are :

- to allow to store a maximal mass of Net Explosive Weight on a site, while respecting rules,
- to avoid transmission of detonation from an igloo to another,
- to avoid, to a certain point, that munitions in exposed sites, be damaged by explosion of munitions in a potential explosive site,
- to protect munitions from malevolence (theft - sabotage),
- to protect munitions from climatic aggressions.

In practice, igloos are storages optimalized for 1.1 munitions, which can be used for other Class-Divisions. When mass-explosion is excluded, it is necessary to rethink igloo design. Let us analyse which igloo feature could become unnecessary, i.e. luxurious.

- earth cover :

- for an exposed site, the earth cover absorbs the shock caused by falling fragments,

- it ensures a satisfactory resistance to a side thrust (explosion of the side igloo)

For a "non 1.1" magazine, the suppression of the earth barricade can be considered if the structure includes a concrete arch. A concrete arch can resist these fragments.

- arch (roof) :

- for a receiver, the arch is calculated to resist the pressure caused by the explosion of a neighbouring donor igloo.

The arch may probably have a lesser resistance (less steel in the concrete arch, for instance) but weakening should be slight. And it's why the reduction of the cost won't be important.

On the other hand, rectangular sections of igloos with or without columns are very advantageous.

These are not so resistant to aerial overpressures and are thus expensive for class 1.1; but they are perfectly suitable for "non 1.1" magazines.

Very large parallelepipedic igloo can be considered (with or without columns)

Figure 2 hereafter compares the two situations.

- front wall :

Most of the existing igloos have a 7-bar pressure resisting front wall.

However some of them have a front wall resisting only a 3-bar pressure.

Igloos having ordinary front walls can be considered, which could resist moderate speed fragments only.

A specific study will show whether the wall is strong enough to have only the minimum distance between the igloos (10 m according to AC 258) or if a larger distance must be complied with.

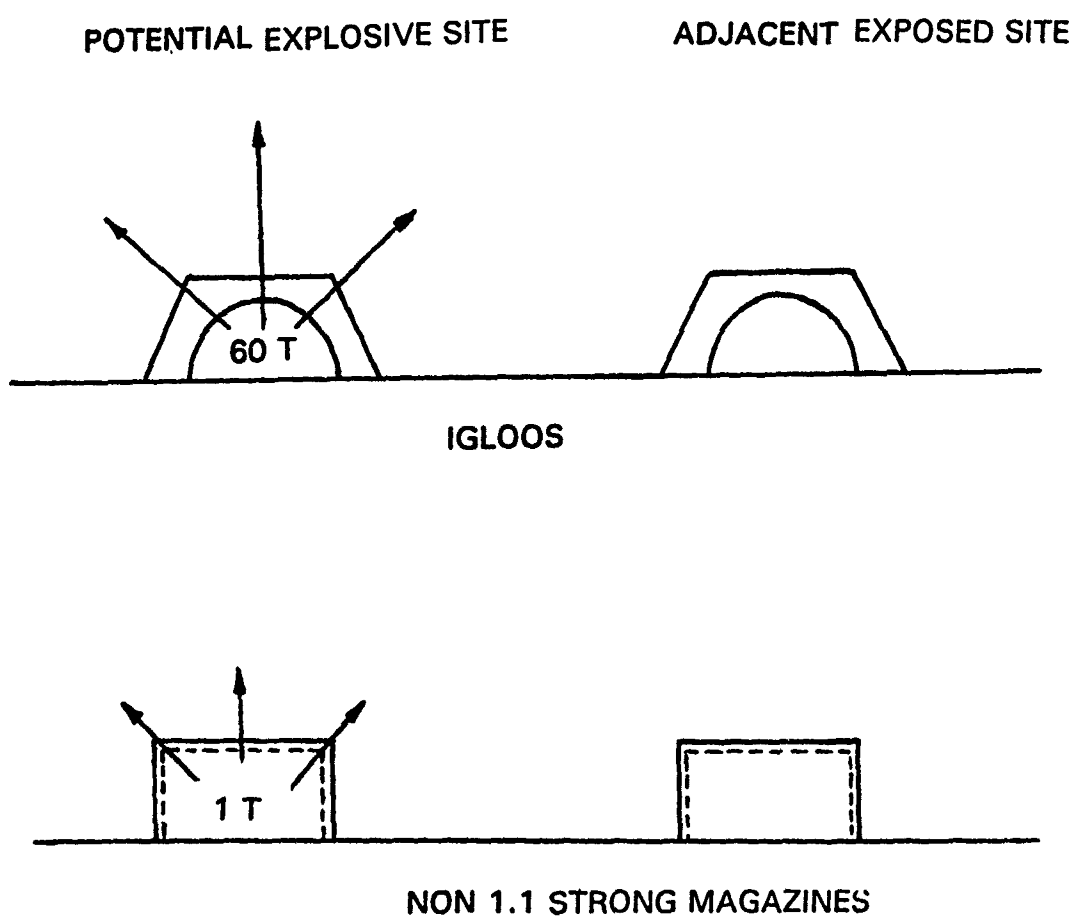

Figure 2 : Interest of "Non 1.1" strong magazines

- <u>door</u> :

The argument for the front is true for the door as well.

- <u>back wall</u> :

The same argument is true for the back wall, which does not need to be protected with earth.

CONCLUSION

The modifications mentioned in the above paragraph can reduce the cost of a magazine yard and lead to the definition of "non 1.1" magazines.

As a matter of fact, as for class 1.1, the number of types may be infinite (the parameters are : door dimensions, with or without columns, span, depth ...) but the rules governing the construction remain unchanged.

2.3. Offer for specific class "non 1.1" magazines

We say that non 1.1 munitions can be stored in igloos designed for 1.1 munitions.

We know that is a *"luxury"* solution but this comfort is difficult to estimate.

SNPE offers two types of "non 1.1" magazines hereunder.

Each type corresponds to a special need but it is clear that each user can define one or several types, depending on is own needs. However, precise rules of construction will have to be respected similary to the present class 1.1 igloos.

In a way, the two offered types are extremes.

<u>TYPE 1 Small "non 1.1" magazine</u>

. Objective :

Creating a strong magazine specific to "non 1.1 munitions", with an optimum cost, but in a class 1.1 igloo yard (already existing or to be built in the future).

. Design :

Non 1.1 magazines can be submitted to heavy overpressures caused by a mass detonation in a class 1.1 igloo.

So they must offer a significant resistance to an external overpressure.

We dont detail this type of magazine in this presentation.

TYPE 2 Large "non 1.1" magazine

. Objective :

Creating strong magazine specific to "non 1.1 munition", with an optimum cost, but far from, or out, of class 1.1 igloo yard.

. Design :

"Non 1.1 magazine" will not be submitted to any significant overpressure.

Very large magazines made of concrete, with columns, are attractive (they also are, sometimes, for class 1.1).

We give hereafter details on a proposed "large "non 1.1 magazine"

The main characteristics are as follows :

- parallepiped with columns,
- large base area (> > 200 m^2)
- travelling crane(s) possible
- no earth barricade
- front wall not resisting 7 bar but moderate speed fragments
- door : same as for front wall
- light reinforcement (objective : to resist climatic conditions and the overpressure caused by the detonation of munitions in a neighbouring magazine).

IGLOO CLASS 1.1	"Large MAGAZINE CLASS NON 1.1"
. width : 8 m	. width : 25 m
. height : 4 m	. height : 4 m
. length : 25 m	. length : 25 m
. N.E.W.: 60,000 kg	. N.E.W.> > 60,000 kg
. area : 200 m^2	. area : 625 m^2
. volume : 630 m^3	. volume : 2,500 m^3
. QD 60T = 870m	. QD 60T = 500m (1.2)
	. QD 240T = 630m (1.2)

Table 1 - Comparison of two classes of magazines

If the user needs a storage surface (with no volume requirement) a "non 1.1 magazine" equals 3.12 class 1.1 igloos.

If the user needs a storage volume, a "non 1.1 magazine" equals 4 type 1.1 igloos.

Figure 3 hereafter presents a compared overview of these two types of magazines

IGLOO 1.1

PROPOSED LARGE STRONG MAGAZINE NON 1.1

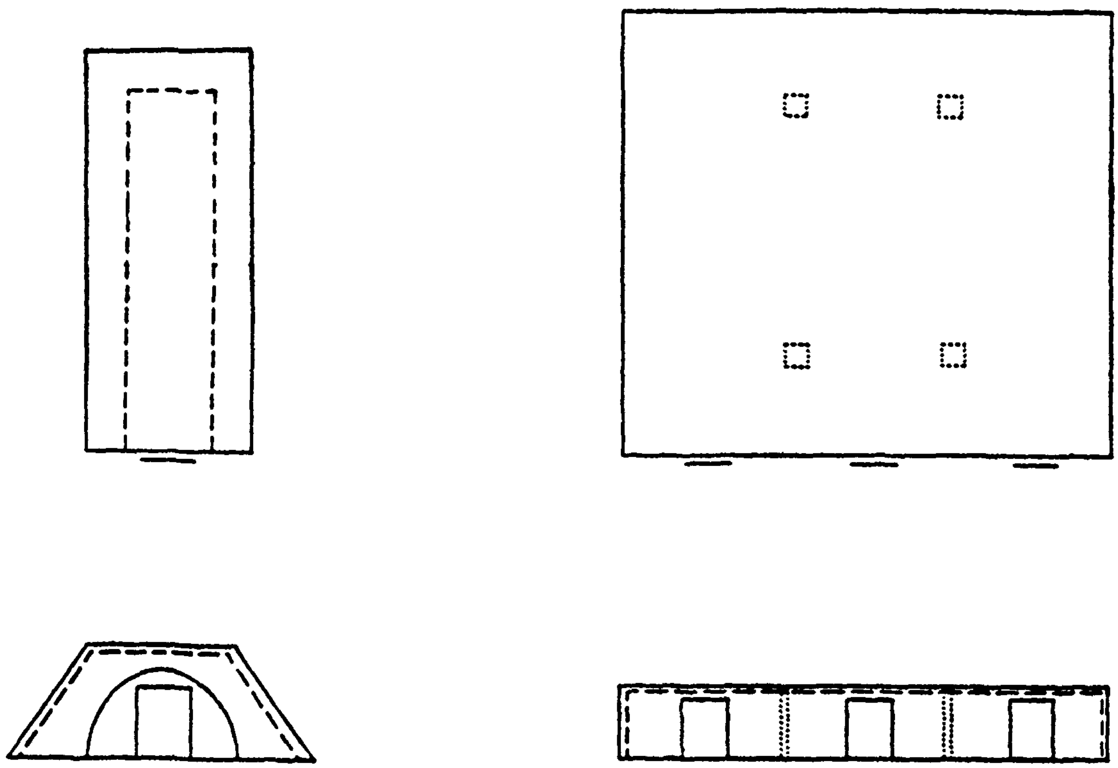

Figure 3 : Overview of magazines

THIRD PART - FINANCIAL BENEFIT ANALYSIS

In this part, we will try to translate technical advantages of the second part in financial benefit. Hypothesises are the same (60 tonnes 1.1 igloo, compared to large class non 1.1 magazine). We will give prices in US $ (1 US $ is taken equal to 5 French Francs).

3.1. Financial benefit from magazines

Lifetime expected from facilities and munitions must be estimated.

We will take for magazines = 40 years
for munitions = 20 years

- In France, cost of a class 1.1 60 tonnes igloo with accesses may be estimated at 330,000 $.

  If divided by two (ratio of lifetimes) and 60,000 kg, cost of building facility is about 3 $ per kg.

  In fact due to the fact that some building remains necessary, benefit is less.

  Another element, is the fact that the occupancy of an igloo may not be up to 60,000 kg of Net Explosive Weight.

  If related to some observation, it may be half, which means than benefit per kg may be doubled.

- The large "non 1.1 magazine" with accesses is cost-estimated at 750.000 $.

<u>ANALYSIS</u>

If the user maintains for the new storage, the same QD as for 1.1 igloo, capacity of the new magazine can go up to 1,420 tonnes of 1.2 according to the $Q^{0.18}$ rule.

In practice, capacity will be limited by the volume or the surface of the magazine.

The new non 1.1 magazine has

- a volume which is 4 times the volume of a 1.1 magazine (ratio of 2,500 m^3/630 m^3)

- a surface which is 3.12 times the surface of a 1.1 magazine (ratio of 625 m^2/200 m^2).

So, capacity of new large non 1.1 magazine will be physically limited from three to four times that of a 1.1 magazine.

Cost comparison gives :

- one large non 1.1 magazine (190 to 240 tonnes) costs 750.000$
---> the cost is 1.6 to 1.9 $ per kg.

- one igloo of 60 tonnes costs 330.000 $
---> the cost is 3 $ kg.

The benefit can be estimated from 1 to 1,5 $ per kg. With a 50% occupancy ratio, benefit can go up to 3 $ per kg of explosives.

3.2. Benefit from gained areas

We will select two prices for the land

- standard country price in France (low price)

  0.2 $ per m^2 or 800 $ per acre ;

- suburban area, very small cities (medium price)

  10 $ per m^2 or 40,000$ per acre.

Situation \ Gain	Total gain in M$		gain in $/kg of explosive	
	0.2$/$m^2$ 800$/acre	10$/$m^2$ or 40.000$ /acre	low price	medium price
A 1 single igloo 60,000 kg NEW	0.320	16	5.4	270
B 10 igloos 600,000 kg NEW	0.360	18	0.60	30
C 100 igloos 6.000,000 kg NEW	0.44	22	0.07	3.5

Table 3 : **Benefits from gained areas**

The difference with buildings, is that benefit from gained areas is obtained <u>once</u>. For an economical evaluation, rate inflation and interest rate should be taken into account, due to the fact that 1 \$ expended to day costs much more, even with a constant \$, than a \$ expended in 10 years.

With an occupancy of 50%, these figures are doubled.

3.3. Overview of benefit - analysis

For a new facility, there is a need to study a combination of benefits from land, and from magazines.

If price of land is medium or high, it's better to maintain small magazines of 60 tonnes, and to maximize gained areas (in § 3.2 we can go up to 540 \$ per kg of explosive).

If price of land is low, and for a large storage it is better to build large "non 1.1 magazines" and gain some area.

Table 4 hereafter presents an overview of estimated benefits

	GAIN ON MAGAZINES	GAIN ON LANDS
Existing Storages	No gain Expected	Large range of gain • small storage, suburban situation : up to 540 \$/kg • large storage - country : 0.07 \$/kg
New Storages	1 to 3 \$ per kg	To be determined - function of price of land

Table 4 : Benefit from giving up 1.1 munitions

(60 tonnes above ground igloo storage)

CONCLUSIONS

Benefits from facilities by using only not 1.1 munitions can be evaluated.

Following NATO rules, benefits according to situation, may vary from almost nothing (existing facilities - very isolated places - large storage) to a considerable amount (540 $/kg of explosive for more populated areas and a single 60 tonnes storage).

Cost-benefit from IM should be further investigated as it is a complex matter depending on rules and situation.

REFERENCES

1 - Life Cycle Cost Model for Defense Materiel Systems - MIL Handbook - 276 - February 1984

2 - "A method for cost-benefit analysis of insensitive munitions" - By A Meller - Pilot Nato Insensitive Munition Information Center

3 - Manual on Nato Safety Principles for the Storage of ammunition and explosives - Nato Manual - AC/258 - D/258

4 - Internal Note "Gained areas from IM Storage" - Note 126/92/GTS - 05 June 1992 by L. ALLAIN

5 - Internal Note "Draft for definition of a 1.2 igloo" 13 April 1992 by J.P. LANGUY

How the Safety of the Ammunition and Explosives
Storage and Handling is Managed in Switzerland

Part I

SAFETY CONCEPT, REGULATIONS AND ORGANISATION

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Abstract:

In Switzerland the safety of storage and handling of ammunition and explosives in the miltary sector has been assessed based on the quantiative risk analysis approach for about 20 years. In this first of three presentations of Swiss participants at the 25th DoD Explosives Safety Seminar the main characteristics of the Swiss safety concept - the main points of view of the notion of safety, the dichotomy of the safety question, the risk definition and the differentiated appraisal of risks - are explained, and the reasons are shown. In addition, the most important safety regulations of the upper and lower level for storage and handling as e.g. the "TLM 75" are introduced. Finally, the main safety organisations and their duties and responsibilities within this concept are presented.

Paper presented at the 25th Department of Defense Explosives Safety Seminar at Anaheim/Los Angeles, USA, 18-20 August, 1992

PREFACE

On the occasion of international contacts, as e.g. the Klotz-Club, the Swiss safety concept in the field of ammunition and explosives and the regulations "TLM 75" which go with it, are often mentioned by Swiss officials or experts. At many international conferences - at the DoD Explosives Safety Seminar since 1976 - Swiss participants read papers on this subject, mainly treating special aspects or interesting details. Although the Swiss concept and the regulations have thus been talked about for several years, it can be doubted that today many of the foreign collegues do exactly know, what this concept actually stands for, and why the Swiss "do it" this way.

This is reason enough for a series of three presentations by Swiss participants at this 25th DoD Explosives Safety Seminar. The presentations are all sponsored by the Defence Technology and Procurement Agency of the Swiss Military Departement with the intention, to let other countries know about the successful Swiss effort in this field and thus, maybe, help them to support their efforts improving the safety of ammunition storage.

This paper is the first of these three presentations. In the second presentation Mr. Peter O. Kummer reads the paper entitled "Risk Analysis of Ammunition Magazines". It gives an idea about how a risk analysis of an ammunition and explosives magazine can be performed.

In the third presentation Mr. Rytz, safety deputy of the Swiss Defence Technology and Procurement Agency, shows a film on construction and mode of operation of the "Klotz", the self-closing safety device for underground storage chambers, which is an essential part of the Swiss effort to enhance the safety of underground ammunition storages.

1. THE REASONS

In the second half of the 60ies a number of problems in the field of ammunition storage arose in Switzerland which could no longer be solved reasonably and economically by means of the existing safety regulations. These regulations were created in consequence of four consecutive and catastrophic accidents which happened in the late 40ies after the second world war. These accidents killed 19 people and inflicted more than 100 mill. SFrs. of damage in the surroundings and to the installations. In addition, roughly 10,000 tons of ammunition were lost. As a consequence, the Swiss government established the Swiss Ammunition Storage Board uniting military and civilian logistic leaders and safety experts. After the investigation of the accidents one of the first tasks of this board was to work out new stringent safety regulations. In essence, these new regulations followed the traditional and widely accepted principles of safety distances to inhabited buildings, and of various hazard categories for different types of ammunition. As another consequence, the construction of the ammunition was improved, less dangerous materials were used especially for the fuzes, and the quality of the stored ammunition was continually controlled.

But already in the 60ies the regulations showed to be too unflexible to response properly to the following three developments:

1. Due to the extension of the artillery and the air force, the amount of ammunition and its explosive content increased steadily. Thus, more storage space was needed.

2. Military readiness requirements called for additional storage space closer to the populated areas and for consumer-friendly, i.e. mixed storage of various hazard categories. Both opposed the common safety requirements.

3. At the same time, in Switzerland a great number of residential, public and industrial buildings, leisure installations and roads were built. The inhabited areas moved closer to the existing installations, and they did not care about safety distances!

The Ammunition Storage Board did not want to stick the head into the sand and increase the number of waivers. In addition, this was not the method to find appropriate sites for new storage installations! And finally, the financial funds were limited as always and anywhere. The Board therefore decided to in-

vestigate the problem thourougnly and in all its dimensions, to find the correct answers to the actual questions and, based on them, to work out new regulations which really would help.

2. THE COURSE OF ACTION

This decision was made easier as the general direction was shown by the first experimental risk analysises performed 1970 for a couple of underground magazines, the capacity of which was limited by the former safety regulation and not for reasons of space. With the risk/filling-relationship calculated individually for every magazine, taking into account the actual human activities in the surroundings, it was shown distinctly, which magazines could be filled beyond the limit given by the former regulation without a bad conscience, and which not (F1).

For the program in mind the Ammunition Storage Board looked for external know-how support and engaged a private consultant. It founded a subcommittee for conceptual decisions, study groups mixed with military and civilian officials and experts, and obtained the necessary funds. The resulting organisation still exists today.

The problem was tackled along the whole front. The questions arousing were numerous. This can be shown with the example of this underground magazine (F2):

- Is the ammunition stored according to the readiness requirements? Can it be taken out in time and in the necessary mixture? Is it protected sufficiently against enemy weapon effects? Has the ammunition to be allocated to more than one chamber?

- Does not safety mean more than no crater in the landscape in case of an event? Could be taken into account that an explosion does not occur every day, that the car driver is exposed only a few moments and the grandmother in the house almost the whole day long to the possible explosion effects? What are actually these effects, and how can they be calculated? What are the possibilities to reduce the explosion effects in the surroundings?

Does every crumb of explosives actually explode and react in the same few milliseconds?

- Is the magazine built economically? What is crucial for the construction and the regular cost? Are there less expensive construction types?

Of course, not all the questions were seen at the very beginning, and due to the limited funds, capacity and capability they had to be answered one after the other and little by little. The priorities were given by the practical needs: new magazines had to be built, i.e. they had to be outlined regarding the requirements and sited safely. A lot of technical data came out of literature studies. Other data was gained by our own tests like propagation tests, model tests for explosion effects or the famous "Klotz"-test in Sweden.

The basic work on methodology and data, and the conceptual decisions were applied immediately on actual examples. Thus, the regulations were already successfully practically tested when they came into force, and that is also why nobody opposed to them.

Initiated by the project of a new assembly plant in one of the ammunition factories of the Military Departement, the virus jumped to the ammunition and explosives handling in factories. Also this activity lacked adequate regulations and criteria which would have allowed safe and economical installations and operation. A study group was founded in the mid-70ies, and together with a private consultant a concept study for the safety assessment in ammunition factories was worked out. A risk analysis of all the working places in one of the factories underlined the feasibility of the quantitative approach also in this field of activities. The findings of this study were applied to the assembly plant project. Lacking technical data for constructions and risk analysis was gained with model tests. A couple of years later, the concept study was adapted to technical regulations, and the safety criteria were harmonized with those of the storage activity.

3. THE METHODICAL CONCEPT

As many discussions show, safety is not understood definitely and clearly. But three important points of view can be distinguished and have to be considered following the Swiss concept (F3):

- The first point of view is the one of the endangered individual. He is focusing his primary interest on his own hazard, judging it based upon his own individual standard, regardless whether or not other people are endangered.

- The second point of view is the one of the anonymous society, who is first of all interested in the total extent of a hazard, as e.g. it appears in accident statistics.

- The third is the aspect of the responsibles for the dangerous activity, in our case the Military Department. They are interested in limiting hazards, such that the public opinion does not question the specific dangerous activity. The Military Departement is e.g. especially afraid of catastrophic accidents that cause much more discussions in the public than smaller but more frequent accidents.

A second important characteristic of the Swiss concept is, that it distinguishes distinctly between the objective, factual part of the safety question and the subjective part which is determined by social values (F4). Very often conventional assessment concepts do mix these aspects, and this is the source of numerous misunderstandings. Corresponding to the structure of the safety question we distinguish betweeen the risk analysis and the risk appraisal.

A third very important element is the quantitative description of the hazard using the terms of risk. Only if hazards are expressed quantitatively, they can be compared with other hazards of the same or other activities, and only this way the benefit of safety measures can be shown reasonably. The risk is given - casually said - by the product of the probability or frequency and the expected damages or consequences of the concerning event (F5). The fatal risk will usually describe the hazards of explosions with sufficient accuracy.

Corresponding to the mentioned three aspects of the safety problem, the individual risk, the real collective risk and the perceived collective risk are distinguished. The individual risk of an endangered person considers the probability or frequency p of the event, the probability t that the person is present when the event may happen and the effects "lambda" on the person in case the event occurs. The real collective risk of an event is given by the sum of all individual risks caused by the event. The perceived collective risk is the real collective risk increased corresponding to the reactions in the public expected after an event. The weighting function is called aversion function and takes into account that the reaction of the public is much more violent to rare events with large consequences than to more frequent events with less consequences per accident. (Definitions and formulas are simplified).

The aim of a risk analysis is to calculate these risks. The risk analysis is a systematic procedure of four steps (F6):

- In the event analysis possible events are identified and described concerning site, type of occurence, probability and size.

- In the effect analysis the dangerous effects of the possible events to persons in the surroundings are determined.

- In the exposure analysis places and time history of possibly exposed persons in the hazardous areas are investigated.

- The risk calculation connects mathematically the parameters deduced from the previous steps.

While the risk analysis part aims at identifying the characteristics of the particular case in question, risk appraisal has to be seen in a wider scope (F7). Methodically it has to be distinguished between the establishment of long-term safety criteria by the responsible persons, and the proof of safety in practical cases when the safety analyst has to prove that the remaining risks do not offend the limits.

The main aspect, under which the individual risk has to be appraised, is equity: Nobody should bear a higher risk than any other person in the same situation (F8). So, the adequate safety criteria are upper limiting values.

In the case of the collective risk, however, upper limits are no longer reasonably applicable. But it seems plausible to rely on how much the society is (and should be) willing to pay for the safety of its members. And everybody agrees, that financial means for safety measures are definitely limited, and should be spent such as to achieve the maximum of safety or the minimum of risk overall. So we have a typical optimization problem. Thus, when appraising the collective risk of an activity, the investment for safety has to be related to the achieved risk reduction, as it is shown in the risk/cost-diagramm at the bottom of figure (F8). One has to go on with safety measures until a certain risk/cost-ratio is attained that has to be regarded by everyone. So, the basic principle to limit the collective risk is the willingness-to-pay-approach, and the safety criteria limiting the collective risk is actually a marginal cost-criteria.

Mind that the willingness-to-pay-approach differs completely from attempts to quantify the monetary value of a human life. There will never be a reasonable and ethically indisputable answer to that question. Ten different people, who would be willing to quantify the values of the human life of ten different persons, would give one hundred different answers. But even people, who would refuse to answer this question because of ethical reasons, would find it necessary to pay money to prevent victims. But, with regard to the value and object of the dangerous activity as well as to the limited funds, they would not go beyond any limit.

Finally, the Swiss safety concept considers that the acceptance of risks depends on the relationship of the exposed person to the hazardous activity, and to what extend he is able to influence his risk (F9). E.g. reality shows that risks voluntarily taken are considered acceptable on a much higher level than those unintentionally run. The difference may be about by a factor of 1000.

Actually, the basis for the Swiss safety criteria is this simplified model which distinguishes four categories of risks. Two of them are relevant in the field of safety of explosives and ammunition: The risk of third persons in the surroundings of a storage or a factory belongs to the category no. 4 of the involuntary and uninfluencable risks. On the other hand, the risks of

people earning their money working with dangerous goods are assigned to the 3rd category of the risks with a low ability to influence and a low degree of self-determination, but a certain perceived benefit.

4. THE REGULATIONS

The development of the explosives safety regulation did not take the ordinary course from top to bottom. The urgent needs came from the practical side as shown in the first chapter. Reality could not wait until the juristical and administrative background would have been set up (which, by the way, would often be very formal and less material), and until the top generals would have had the time to set priority to safety problems which they never had been confronted with, since never a relevant accident had happened during their career. But it can be said that today the concept would withstand any formal or material attacks.

On the highest level the Swiss Explosives Law releases the military forces and the military administration from the substantive contents of the law, but commits the Government to issue its own concepts and regulations for this field (F10). The Governement assigned the duty to the Military Departement, which designated the chief of general staff as the responsible for the safety of the handling of ammunition and explosives by the forces and the administration.

The chief of general staff enacted the "Directives Concerning the Safety of the Handling of Ammunition and Explosives by the Military Forces and the Military Administration (German abbreviation "WSUME"). They lay down

- the general qualitative safety goal (e.g. the protection of human life and freedom from injury),

- the safety assessment concept and planning mode based on quantitative risk analysis (as shown in chapter 3),

- the quantitative safety criteria, i.e.
  - upper limits for the individual risk,
  - aversion values for calculating the perceived collective risk and
  - marginal cost per human life to be saved for the appraisal of the perceived collective risk,

  with regard to the risk category of the risk bearers,

- the duties and responsibilities of the subordinate levels (they are precised in the other concerning official regulations which were adapted in this matter),

- the policy for the information of the public.

The "TLM 75" are the regulations for the ammunition and explosives storage in peace time, an activity several agencies of the Military Departement are concerned with (F11). "TLM" is a German abbreviation and stands for "Technical Regulations for the Storage of Ammunition". "75" means that they were initiated in 1975. The TLM 75 are a set of five parts:

- Part 1: "General Principles"
  - describes the general aspects and criteria of the ammunition storage,
  - outlines the main construction possibilities for magazines for certain applications,
  - defines the jobs to be done in the typical course of planning and realizing or renewing of storages (e.g. it demands an optimization process for the planning of a new magazine to be sited or renewed, and a detailed safety assessment as a basis for a safe storage and operation of the magazines) and
  - designates duties and responsibilities of the military and civilian agencies involved (the magazines are built by the civilian Federal Buildings Office).

- Part 2: "Safety Assessment" (F12)
  - summarizes principles and models for quantitative safety assessments,
  - contains methodology and technical data necessary to perform individual risk analyses of a certain magazine in the crucial steps of the planning, realisation and storing procedure and
  - gives criteria for the individual risk appraisal of a particular magazine to fix its safe storage.

  Thus, TLM 75/Part 2 is both a regulation and a technical handbook.

- Part 3: "Planning and Construction of Magazines"
  . contains the basics for planning, siting and construction of magazines of different construction types like underground, shallow-buried, earth-covered and freestanding above-ground, and
  . describes geometry and construction including important structural details of the common storage types and additional structural safety measures such as e.g. the "Klotz"-device.

- Part 4: "Storing of Ammunition"
  . stipulates how the ammunition has to be stored in the several types of magazines regarding readiness aspects and safety limits obtained in the risk analysis and
  . contains the values to calculate the representative TNT-quantity of an ammunition storage.

- Part 5: "Storing of Ammunition by the Troops"
  gives principles and basics for the safe storage of ammunition by the troops.

These parts are upgraded periodically with regard to the improvements of methodology, models, data and criteria, as well as to new needs and to the developments in the civilian branch of safety and of the public opinion. At the moment, the revised Part 2 comes into force, and Part 4 is under revision.

For the safe handling of ammunition and explosives in the ammunition and propellant factories the chief of the concerning agency set the WAE into force (F13). "WAE" is a German abbreviation for "Directives for the Safety in Federal Armament Factories with Explosives Hazards". It consists of two parts:

- Part I : "General Principles and Responsibilities"
  . describes the general safety concept,
  . gives the qualitative safety goals,
  . defines the occasions when safety assessment jobs have to be done,
  . who is responsible for them and
  . how they should be done.

- Part II: "Guidelines to Perform Safety Assessments"
  . contains the methodology and models to perform quantitative risk analyses of explosives safety problems in the factories, such as for defining

safety levels or for planning procedures,

. gives safety criteria for the risk appraisal.

There is no technical data in this part. A lot of know-how is given by the technical data appended to the numerous safety assessments performed.

For the transport, the third large activity with ammunition and explosives, the concepts and the regulations are not yet worked out. You cannot be dancing at all the weddings! The transport was given second priority, because there are a lot of civilian regulations that have to and can be regarded without severe problems apparently. This year, a first step will be done to investigate if transport safety is also given in the sense of the quantitative safety concept.

5. THE ORGANISATION

Many different military and civilian agencies are involved with ammunition and explosives storage. Therefore coordination is necessary for an economical management with a maximum safety benefit. For this purpose several permanent bodies were founded over the years (F14).

There is the Ammunition Storage Board, today called "Committee for the Safety of Handling of Ammunition and Explosives by Forces and Administration", consisting of the Deputy Chief of Staff Logistics as chairman, the Deputy Chief of Staff Instruction and a Vice Director of the Defence Technology and Procurement Agency. This committee advises the Chief of General Staff concerning storage and ammunition and explosives safety. It leads and coordinates the management of the storage, development and revisions of regulations and the basic research in this field.

Aside stand a safety deputy and a "Project Committee" with advisary functions. The safety deputy is the safety expert of the Committees and the Military Departements risk manager for the ammunition and explosives storage. The Project committee consists of a dozen high-ranked members of all the military and civilian sections concerned with ammunition and explosives procuring, fa-

brication, transport and storage, and the leaders of the studygroups. Its duty is to find the numerous optimums in this field!

Committee and Project Committee meet once or twice a year.

The decisions are prepared and the work is done by a number of study-groups:

- The team "Basics" works on long term projects and cares about methodology, models, data and criteria for safety assessment and risk management on several levels of ammunition and explosives handling. It is the oldest team, and it is this team which has performed the first risk-analyses more than twenty years ago. It consists of half a dozen of experts from the administration, among them the Committee Safety Deputy, and private consultant experts. It is led by the safety deputy of the Defence Technology and Procurement Agency.

- The five teams "TLM" take care of the regulations TLM 75. Their four to eight members come from several agencies concerned and from private consultants, and are specialists or managers. They are led by experts from the concerned military and civilian agencies.

- The three management teams are working on improvement concepts and on overall concepts for storing the ammunition for Army and Air Force. They have also about half a dozen of members and leaders who come from several agencies.

The hard core of these study groups consists of about half a dozen people. Some of them have been in action for more than 20 years.

For the safety in fabrication no special organisation had to be created, because it can be ensured by the existing structures. There is only an expert team consisting of the safety deputies of the factories who exchange know-how and experiences. In the field of transport there is no special organisation at the moment, but it is possible that there will be a study-group embedded in the organisation shown above.

6. BENEFIT

There are three main advantages our concept, regulation and organisation have brought over the years (F15):

- The methodical concept of quantitative safety assessment makes the hazards of ammunition and explosives handling comprehensibly and intelligibly visible, and comparable. The reponsible people know actually the responsibilities they bare.

- There are regulations that can actually be applied. There are distinctly less waivers compared to former times. The risk peaks were reduced drastically (F16) which can be shown in this diagram presenting the risks of a number of aboveground magazines by 1980 and 1988.

- The necessary safety level can be achieved economically. The flexible assessment concept allowed constructions economizing millions and millions of SFrs.

  Major General Bender, former chairman of the Ammunition Storage Board, read a paper on the Swiss experiences with risk management at the 22nd DoD Safety Seminar 1986 also in Anaheim (F17). He then compared an actual Swiss situation with 20 above-ground magazines following NATO- respectively TLM 75-principles. It showed that NATO-principles would necessitate more than twenty new magazines causing cost about 10 million SFrs., and for many of which new sites could not have been found.

How the Safety of the Ammunition and Explosives Storage and Handling is Managed in Switzerland

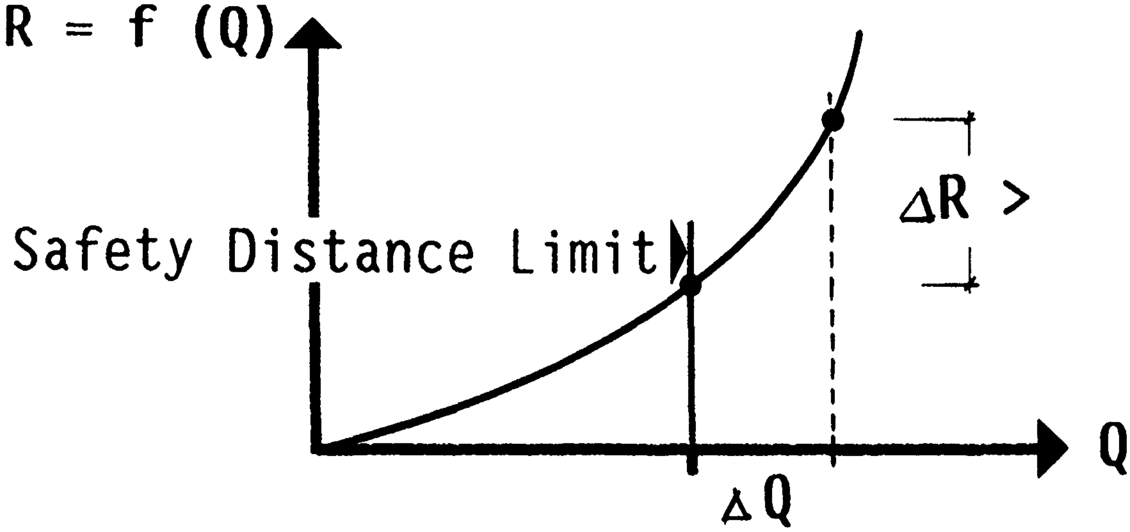
Part 1:

Safety Concept, Regulations and Organisation

Andreas F. Bienz
Bienz, Kummer & Partner, Zollikerberg
on behalf of the Swiss Defence Technology and Procurement Agency

Result of First Risk Analyses

Case 1: no additional filling possible
because $\Delta R / \Delta Q >$



Case 2: additional filling reasonable
because $\Delta R / \Delta Q \ll$

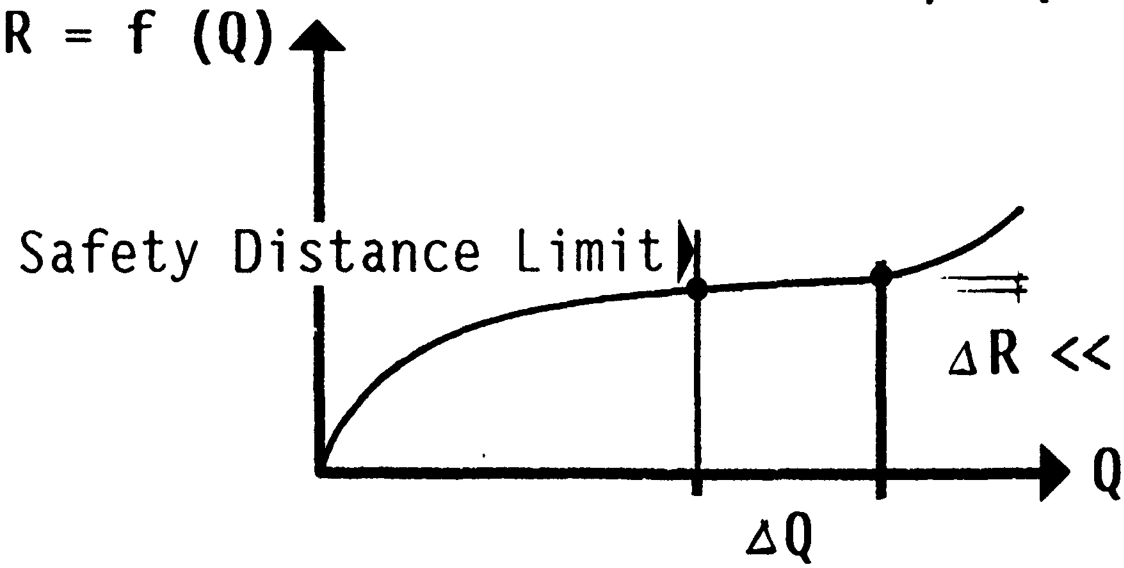


Figure 1

Integrated Problems

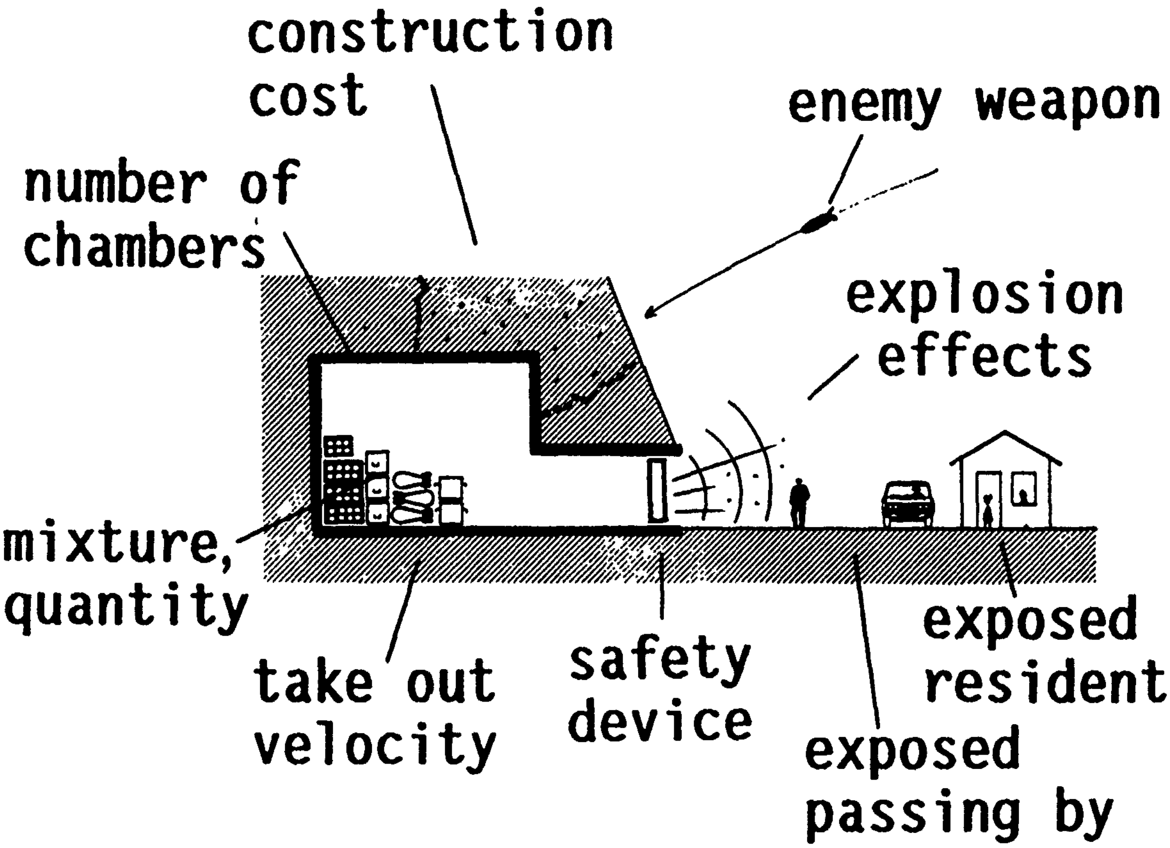


Figure 2

Safety: Main Points of View

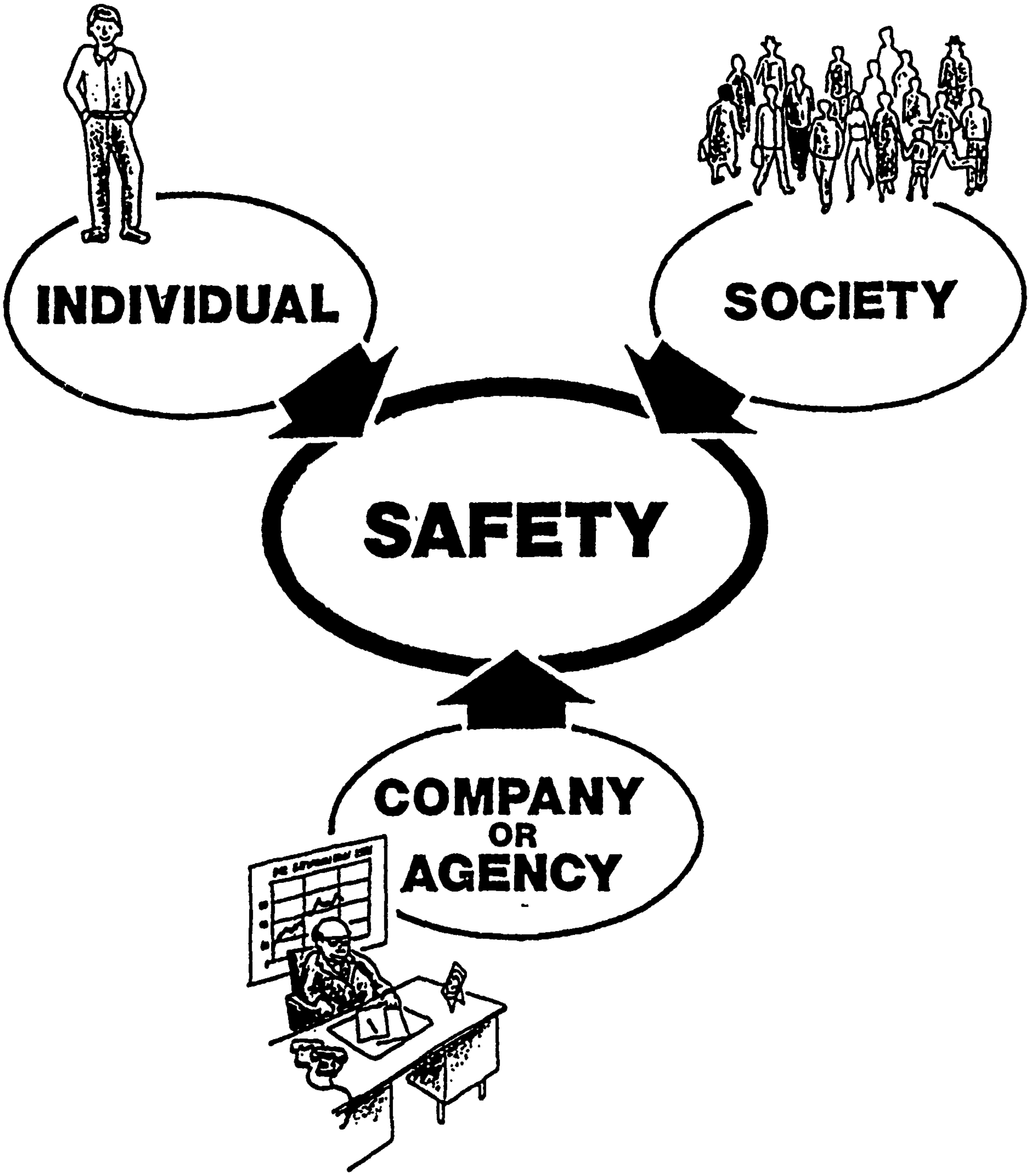


Figure 3

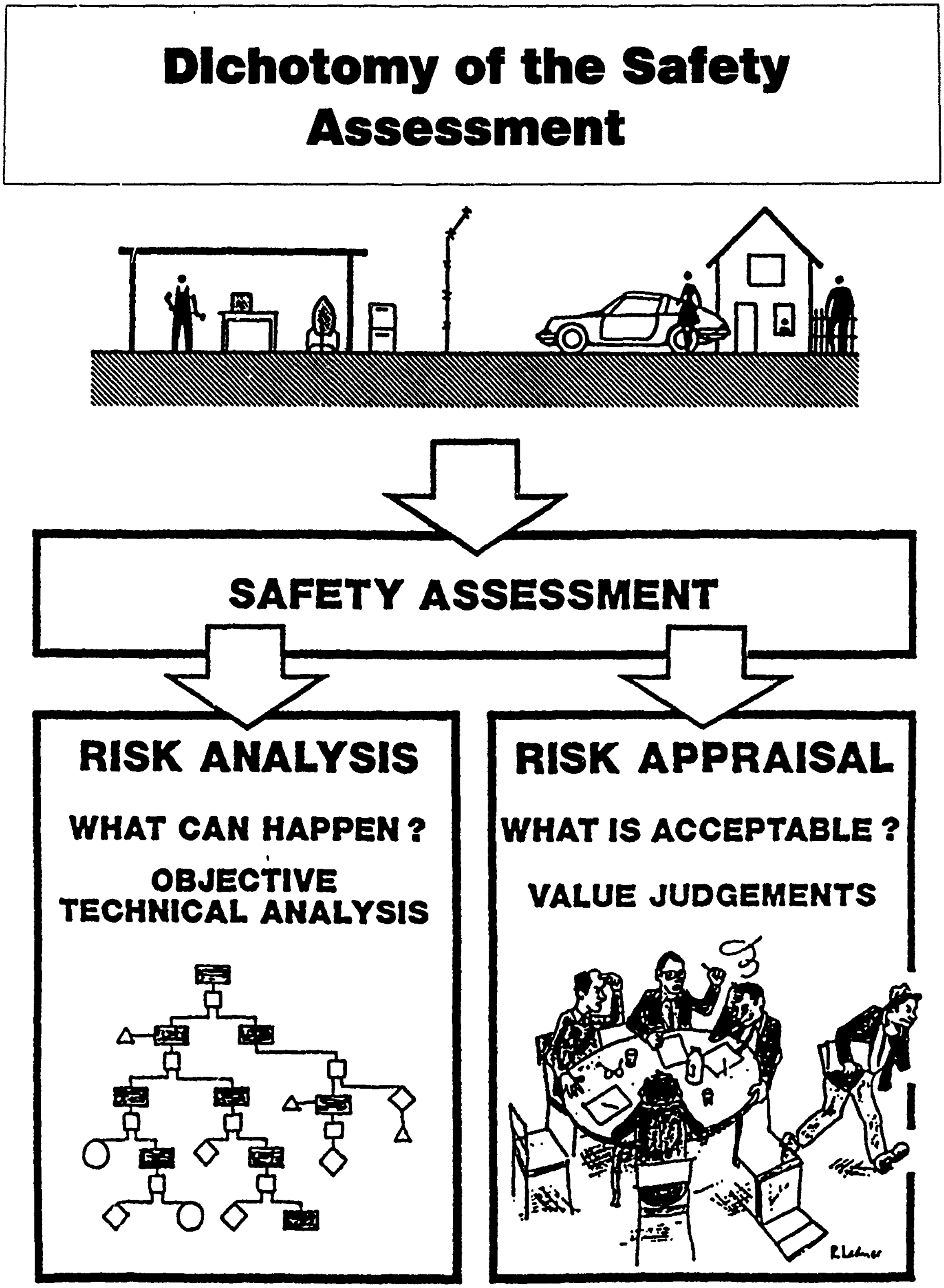
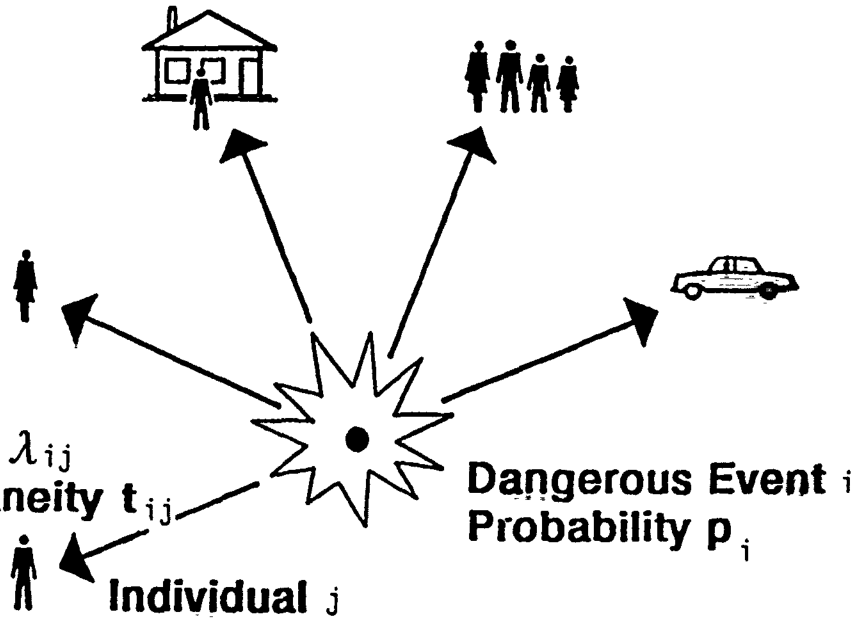

Dichotomy of the Safety Assessment
SAFETY ASSESSMENT
RISK ANALYSIS
WHAT CAN HAPPEN ?
OBJECTIVE
TECHNICAL ANALYSIS
RISK APPRAISAL
WHAT IS ACCEPTABLE ?
VALUE JUDGEMENTS

Figure 4

Hazards Expressed Quantitatively

Risk = Probability x Consequences [1]



Individual	Society	Company

Individual Risk	Real Collective Risk	Perceived Collective Risk
$r_{ij} = p_i \cdot \lambda_{ij} \cdot t_{ij}$	$R_r = \Sigma_i \, p_i \cdot \lambda_{ij} \cdot t_{ij}$	$R_p = \varphi \cdot R_r$ [1]
		φ = Aversion

[1] Simplified

Figure 5

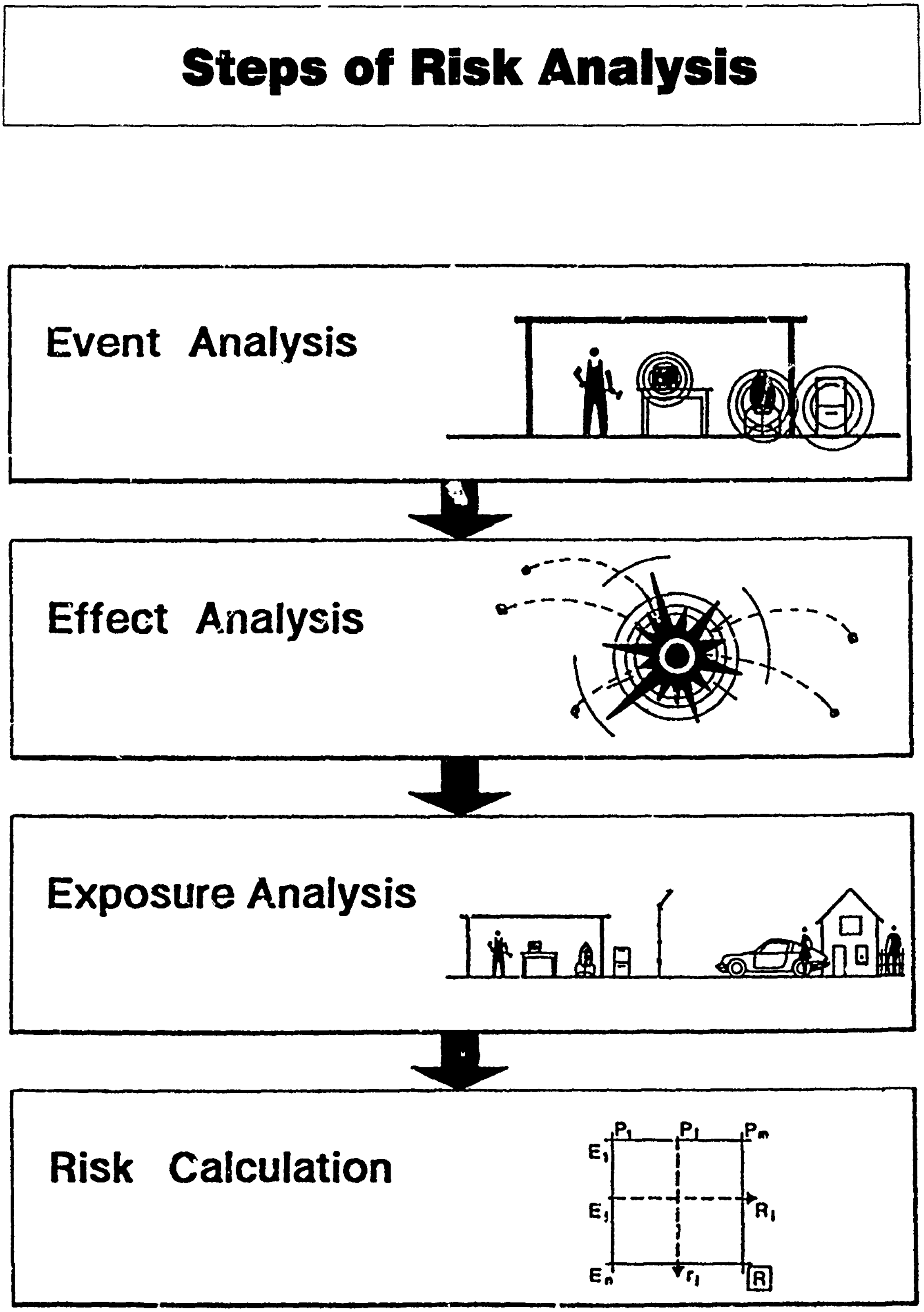
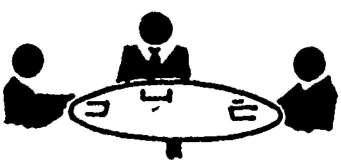

Steps of Risk Analysis
Event Analysis
Effect Analysis
Exposure Analysis
Risk Calculation
P1
Pj
Pm
E1
Ej
Ri
En
rj
R

Figure 6

Levels of Risk Appraisal

Responsibles



Definition of Safety Criteria

Application

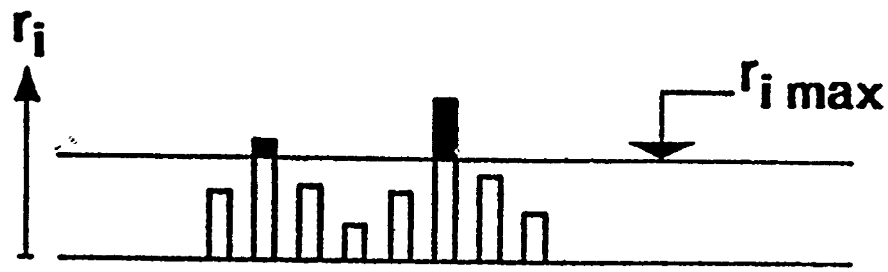
Proof of Safety

Application of the Safety Criteria in the Actual Case

Figure 7

Types of Safety Criteria

- **INDIVIDUAL RISK:** EQUITY
  => UPPER LIMITING VALUES



- **COLLECTIVE RISK:** LOSS MINIMIZATION
  WILLINGNESS TO PAY
  => MARGINAL COSTS

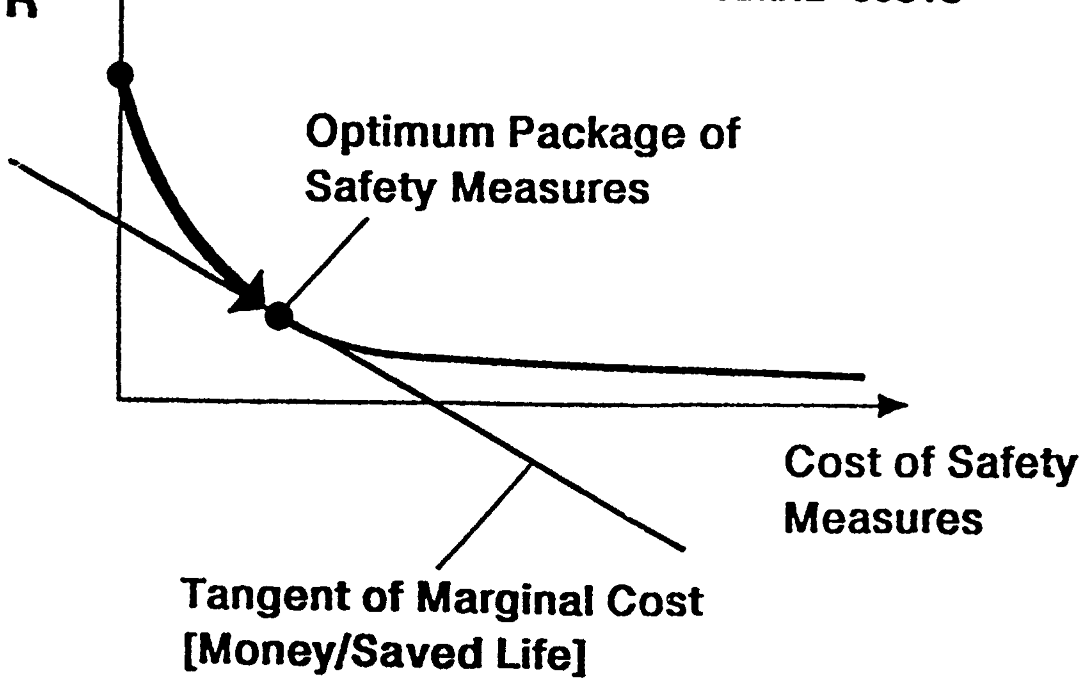


Figure 8

Differentiated Appraisal of Risks: Influencing Parameters

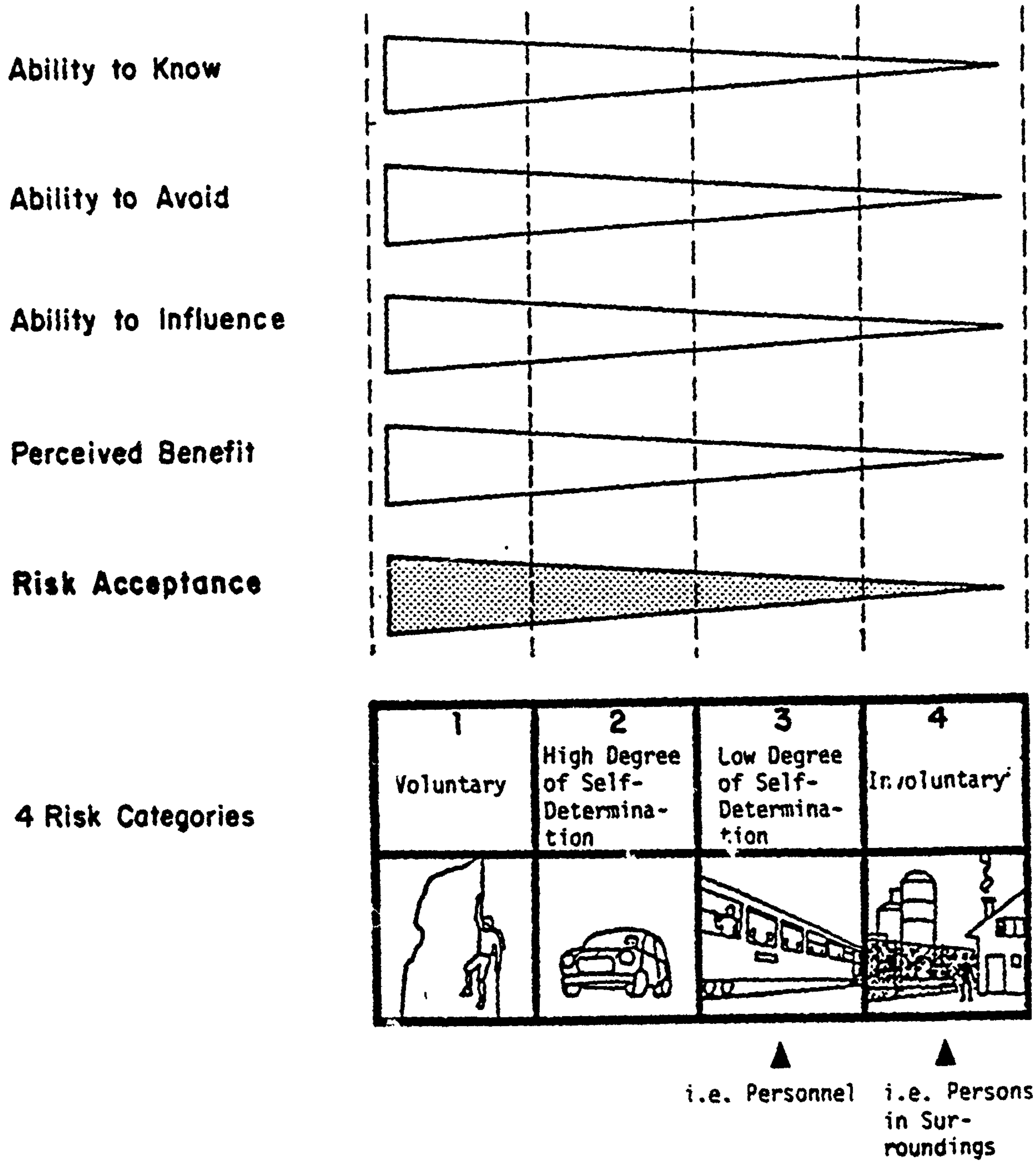


Figure 9

Superior Regulations

Swiss Explosives Law

↓

Government

↓

Military Department

↓

Chief of General Staff

↓

"Directives Concerning the Safety of the Handling of Ammunition and Explosives by the Military Forces and the Military Administration"

(WSUME)

- **General Safety Goal**
- **Quantitative Safety Assessment Concept**
- **Quantitative Safety Criteria**

Figure 10

Regulations for Ammunition Storage

"TLM 75"

"Technical Regulations for the Storage of Ammunition"

Part 1 : "General Principles"

Part 2 : "Safety Assessment"

Part 3 : "Planning and Construction of Magazines"

Part 4 : "Storing of Ammunition"

Part 5 : " Storing of Ammunition by the Troops"

Figure 11

TLM 75/Part 2: Safety Assesement

- Principles and Models for Safety Assessments
- Methodology and Data for Risk Analyses
- Safety Criteria

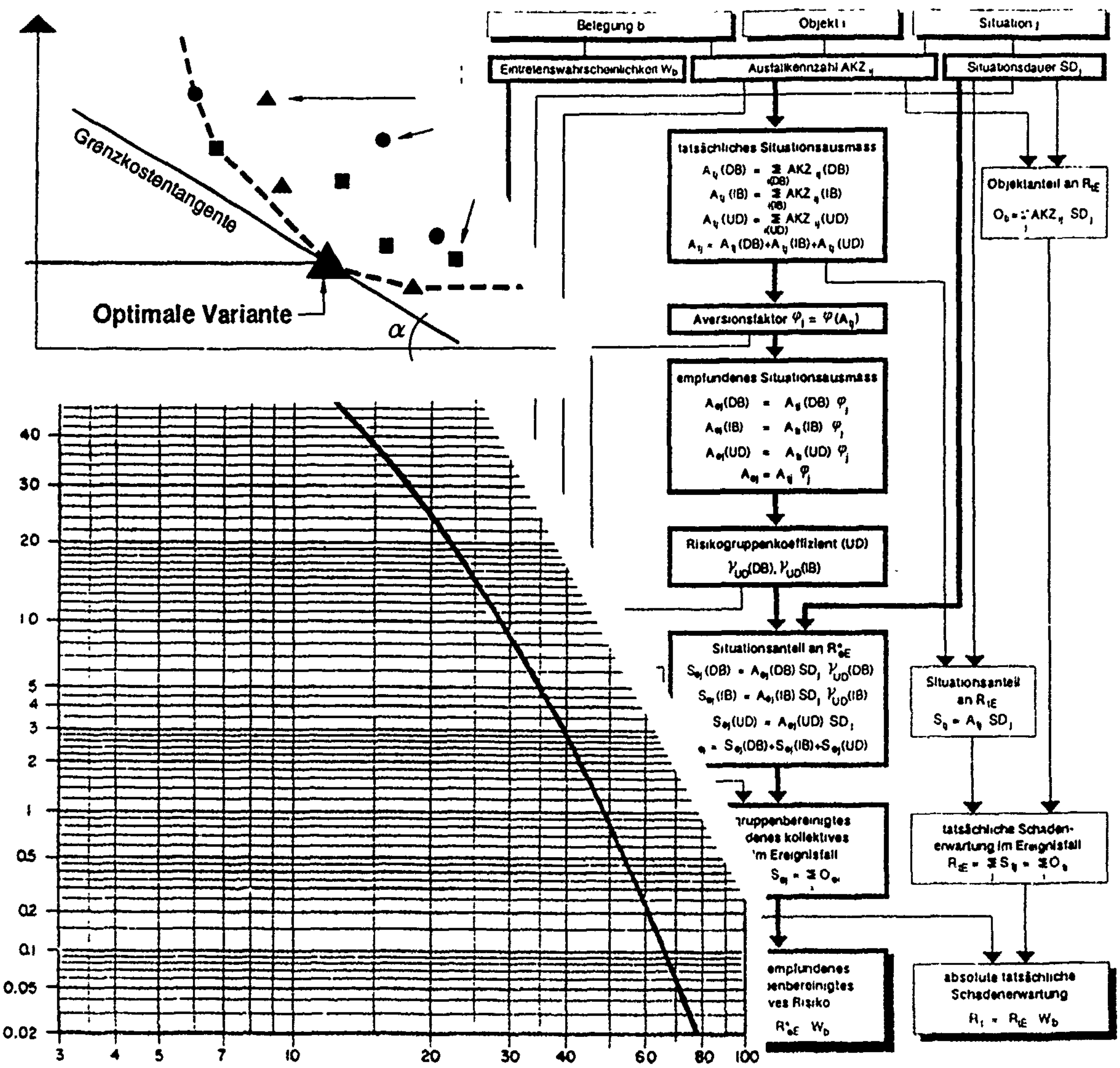


Figure 12

Regulations for Ammunition Fabrication

"WAE"

"Directives for the Safety in Federal Armament Factories with Explosion Hazards"

Part I : "General Principles and Responsibilities"

Part II : "Guidelines to Perform Safety Assessments"

Figure 13

Ammunition Storage Committees

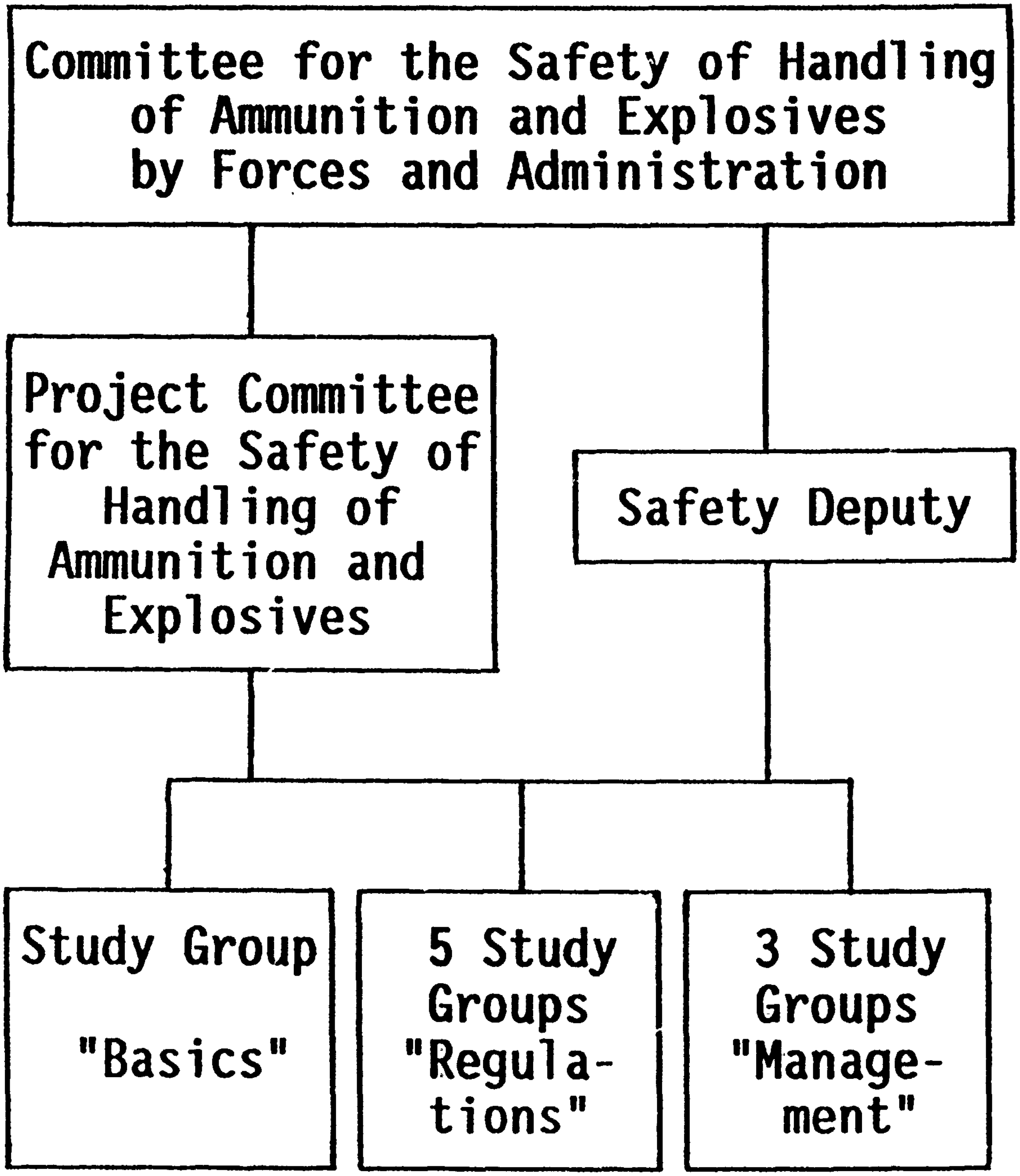


Figure 14

Main Benefit

- Hazards are
  - comprehensibly visible
  - quantitative : comparable

- Regulations can actually be applied, few waivers

- Economics

Figure 15

Risk Peaks 1980 and 1988

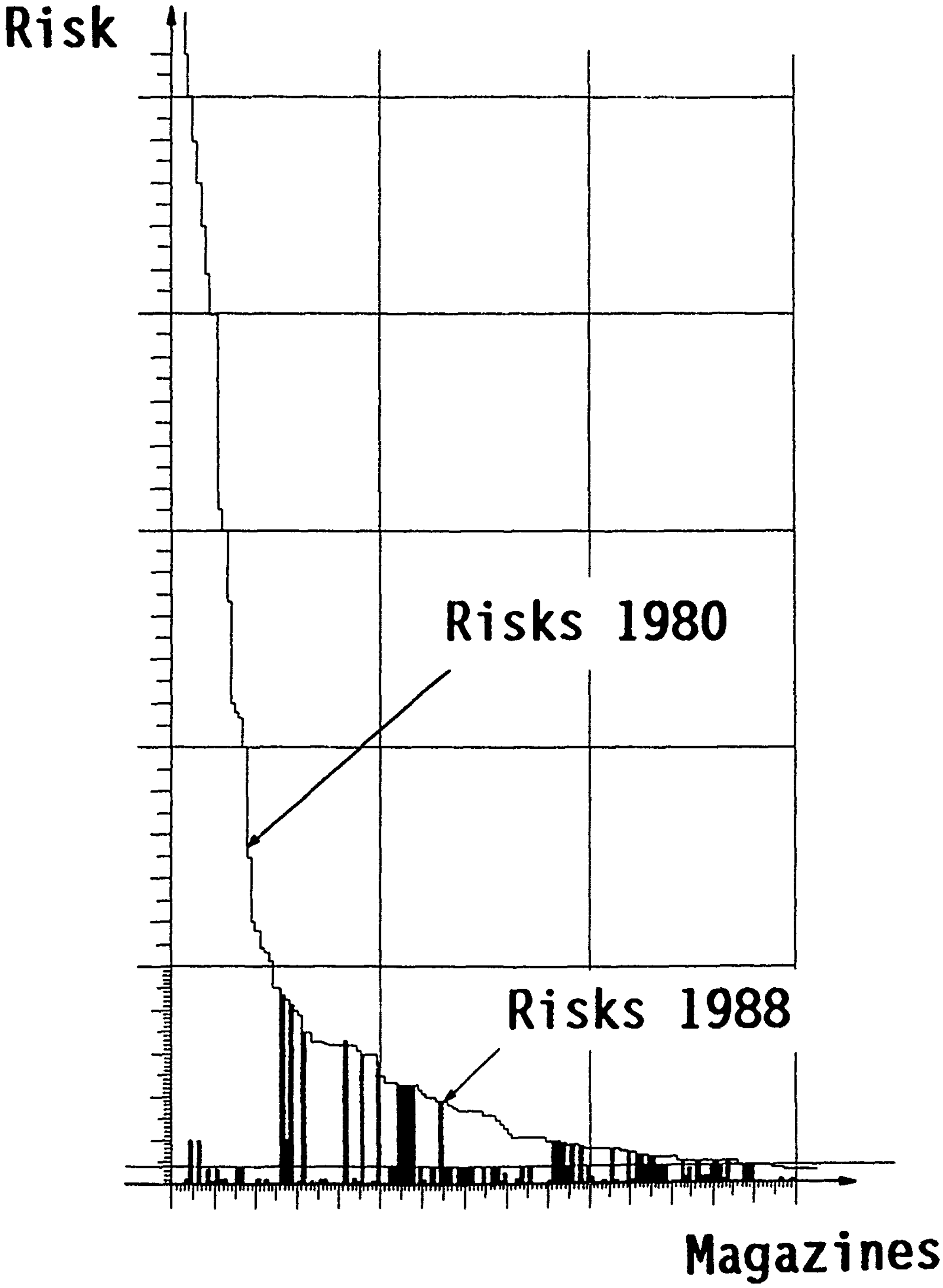


Figure 16

NATO-Regulations versus TLM 75

- 20 Freestanding Storages in a Actual Region in Switzerland

- Required Storage Capacity in Region: 2100 Tons

COMPARISON	SWISS REGULATION	NATO SAFETY PRINCIPLES
Admitted for Ammunition Storage	19	7
Remaining Storage Capacity	2100 Tons	500 Tons
New Storages • Number	None	23
• Costs	None	~10 Mio SFr.
Total Number of Storages	19	~30
Accepted Total Risk From All Storages	1 Fatality in 1700 Years	1 Fatality in 2200 Years

Figure 17

How the Safety of the Ammunition and Explosives
Storage and Handling is Managed in Switzerland

Part II

RISK ANALYSIS OF AMMUNITION MAGAZINES

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Abstract

In Switzerland the safety of the storage and the handling of ammunition and explosives in the military sector has been assessed based on a quantitative risk analysis approach for nearly 20 years. This paper, the second of three presentations by Swiss participants at the 25th DoD Explosives Safety Seminar, shows how quantitative risk analysises for ammunition magazines are performed. The main steps of the risk analysis, the event analysis, the effect analysis and the exposure analysis are discussed and the risk calculation procedure is explained as well. It is shown which regulations exist, which physical models are used, what they are based on and how to proceed. Furthermore, the computer tools which are used today, and the planned developments are discussed.

Paper presented at the 25th Department ot Defense Explosives Safety Seminar at Anaheim/Los Angeles, USA, 18-20 August, 1992

PREFACE

This is the second paper in a series of three presentations at the 25th Department of Defense Explosives Safety Seminar by Swiss participants. The main topic of all three presentations is how Switzerland manages the safety problems arising from the handling and storing of ammunition and explosives in the military field.

Paper one, presented by Mr. Andreas F. Bienz, deals with the safety concept which is based on a quantitative risk analysis approach and was introduced in Switzerland already 20 years ago. The main points of view of safety, the dichotomy of the safety question, the risk definition and the risk appraisal are explained, and their advantages are shown. In addition, the regulations for safety on the highest level and those for storing of ammunition, the "TLM 75" are introduced as well as the corresponding regulations for the fabrication of ammunition. Finally, the main safety authorities and their duties and responsibilities within this concept are shown.

Presentation three, by Mr. Hansjörg E. Rytz, is a film about the famous "Klotz", which is an essential part of the Swiss effort to enhance the safety of underground ammunition storages. The film shows the benefit of using the Klotz-device as a special safety measure as well as the construction of the Klotz in detail.

All three presentations are sponsered by the Defense Technology and Procurement Agency of the Swiss Federal Department of Defense. It is the intention of this agency, to let other countries know about the successful Swiss effort in this field and thus, maybe, help them to support their own efforts to improve the safety of the handling and storing of ammunition.

CONTENTS

1. INTRODUCTION

Until the early seventies, the safety of ammunition storages in Switzerland was assessed with a safety distance model. Meaning, that the permissible storage capacity of the magazines was mainly based on safety distances between the magazines and endangered objects in the surroundings, like houses and roads. A model, which is still used in many countries today.

Due to the fast increasing population density and the increased need for storage room at that time, it was no longer possible to observe the regulations, and numerous waivers were the result. At the end, a major part of all ammunition storages had to live with waivers, and nobody did really know if it was a real safety problem or not. Due to this situation, Switzerland was forced to search for a more innovative safety approach.

The result was a safety concept, which allows Switzerland today to manage its system of ammunition storages with a low overall risk and acceptable costs. Moreover, additional aspects like readiness and protection against enemy weapon effects can be taken into account to optimize the system. This concept is layed down in the regulations "TLM 75" and "WSUME" [ref. 1, 2].

The Swiss safety assessment concept consists of two main parts, a quantitative risk analysis and a risk appraisal (fig. 1). Whereas the first part gives an answer to the question "What can happen?", the second part answers the question "What is allowed?", or in other words, the magnitude of the risks are compaired with the risk criteria or the accepted risks.

The aim of this paper is to explain how a quantitative risk analysis for an ammunition storage can be performed, what our tools are and what experiences we made so far. The risk appraisal is not discussed in this paper, for more information refer to paper one [ref. 3].

2. PROCEDURE OF THE RISK ANALYSIS

2.1 Definition of Risk

To understand the procedure of the risk analysis, it is necessary to introduce the term "Risk" at first. It is generally accepted today that "Risk" has to be at least a function of the consequences as well as of the probability of a possible accident.

In Switzerland, for the safety assessment of ammunition storages the two terms "Individual Risk" and "Perceived Collective Risk" were assigned as decisive (fig. 2). The "Individual Risk" is the probability for a single person to be killed in an explosion. The "Perceived Collective Risk" expresses the total potential consequences of an accident. By means of the aversion factor, it is taken into account, that accidents with large consequences are judged as more serious than a couple of smaller accidents with an equivalent loss. Further, it is to mention, that we assume fatally injured persons to be the significant value for the calculation of the consequences.

It is not the aim of this paper to discuss the risk definition in detail. For more information about this subject refer to reference 3. On the following pages it will be shown however, how these risks are calculated.

2.2 General Steps

The typical procedure for the calculation of the risks consists of the following three main steps (fig. 3):

- event analysis
- effect analysis
- exposure analysis

These three so called "creative steps" are followed by the risk calculation which is a "pure numerical connection" of the results from the previous steps.

2.3 Event Analysis

The event analysis should answer the questions about the

- probability,
- magnitude and
- type of reaction

of a possible event. Of course, it is assumed that the location of the event is in the storage room.

To calculate the **probability** of a possible event in an ammunition storage, a model was elaborated some years ago, which takes the following parameters into account:

- type of construction of storage (above-ground, underground ...)
- gross tons of the stored ammunition
- fire fighting and detection systems in connection with special storing conditions (non-massreacting mixture)

The model to calculate the probability p has the following form (fig. 4):

$$p = A + B \cdot X$$

This model assumes that an explosion can be triggered either by ammunition internal causes like corrosion in igniters or decomposition of the propellant, or by external effects like sabotage or lightning. The term A takes external effects into account. It mainly depends on the type of construction of the storage which determines the degree of the outer protection of the stored ammunition. The term A is defined as a constant for each type of storage.

Factor B considers all ammunition internal effects which could lead to an explosion. It is a specific value for 1 gross ton of ammunition, independent of where the ammunition is stored. Only in case of an non-massreacting ammunition mixture, in connection with a fire detection and -fighting system in the storage room, this factor can be lowered.

Factor X relates to the total amount of stored ammunition in one chamber expressed in gross tons.

Of course, at the first glimpse this model seems to be quite simple. Many parameters like the sensitivity of the different ammunition types, the age of the stored ammunition and the frequency of the ammunition transfer, as an example, which surely also have an impact on the event probability, can't be taken into account. But until today, nobody could offer a more plausible model which considers all these different parameters. So, in Switzerland we are convinced, to have the most suitable available model for the calculation of the event probability of ammunition storages, today.

The second important value of an explosion event is the **size of the explosion,** i.e. the quantity of explosives taking part in the event. It can be calculated with our regulation TLM 75/Part 4 [lit. 1]. This part of the regulation contains for each type of ammunition, which is in use in the Swiss army, the relevant TNT quantitiy to calculate the representative event as basis for the effect analysis.

As we distinguish four different types of storage constructions - above-ground magazines, earth-covered magazines, shallow-buried magazines, magazines in rock

with and without Klotz device - and two ammunition mixtures - a mass detonating and a non mass detonating - eight TNT quantities had to be defined for each item. The representative TNT quantity takes into consideration such important things as the TNT-equivalent of the explosive in the item, the packing conditions and the casing factor which depends on the ratio weight of steel casing to weight of explosive in the item. The representative TNT quantities of the items had been evaluated by hundreds of live propagation tests and a specially developed theoretical model.

In practice, to evaluate the representative event, the number of stored items are simply to be multiplied with the respective representative TNT quantity of each item (fig. 5).

Our regulations do not define hazard categories as other regulations like e.g. the NATO-regulations do. As outlined above, in Switzerland we store our ammunition in a mixed way and do not distinguish so called compatibility groups also, except for a small number of items. That means, propellants, grenades, fuses etc. are all stored in the same magazine. Therefore, we always can assume that the **reaction** representative for the hazard, **is an explosion/detonation.**

This mixed storage shows many advantages compared to the separated storage of different items. Besides the much better readiness and enemy protection of the ammunition, it offers also much more flexibility to managing the storing, and thus allows a more cost-effective operation of the system.

Now, all relevant parameters of the event analysis are defined. The probability of the event "goes" straight into the risk calculation. The size of the event in terms of the representative TNT-quantity however, is the input for the effect analysis.

2.4 Effect Analysis

In the effect analysis we calculate all the relevant explosion effects, which may endanger people in the surroundings of an ammunition storage, and the impact on them. The results are the lethalities (probability to be fatally injured by the event) of the exposed persons.

Just as an example, in case of an explosion in an underground magazine we consider the following explosion effects (fig. 6):

- air blast from the access tunnel
- debris throw from the access tunnel
- cratering above the storage chamber
- air blast from the crater (if cratering occurs)
- debris throw from crater (if cratering occurs)
- ground shock

All physical models to calculate these effects and the corresponding lethalities are contained in our regulation TLM 75/Part 2 [lit. 1]. Figure 7 shows a typical diagram of the air blast spreading from an above-ground magazine.

The models we use, are based on our own test series performed especially with shallow-buried and above-ground magazines [lit. 4,5], tests Switzerland performed together with other nations, like the Klotz-Club tests, and on evaluations of test reports from other nations.

As Switzerland is one of the founding nations of the Klotz-Club and still an active member, we become aquainted with the latest reports in this field. With this information we try to upgrade TLM 75/Part 2 to the state of the art from time to time, as we do with the other parts of our regulations.

2.5 Exposure Analysis

The main aim of the exposure analysis is to ascertain where in the surroundings and how long how many people are exposed to the potential explosion effects. Other than in a quantity distance model not only distances to exposed objects are measured, but also a detailled "time table" is worked out. As an example, it is of interest

- how many people live in an exposed house,
- how often a parking lot is used by how many cars with how many passengers,
- how many trains with how many passengers pass a magazine a day
- or how many cars pass by on a road during the day, the night and on weekends.

The following objects - meaning places where persons stay for some time or pass by - are considered in the exposure analysis:

- persons outdoors, like on a free field, in a forest, on a sports ground, in a garden or on a mountain trail,
- persons in houses (different construction types are distinguished),
- persons in cars and
- persons in trains.

Figure 8 gives an example of such a "time table" for a specific storage. Characteristic for this procedure is, that we divide a typical week "in the life" of an ammunition storage into so called "situations", during which we assume that the number of exposed persons and the exposed objects are constant. The reason for this is, that we judge situations with a lot of exposed persons as more serious than situations with a small number of endangered people. This "time table" allows us to assess this aspects in the risk calculation.

2.6 Risk Calculation

This step of the risk analysis, the risk calculation, numerically connects the data gathered from the preceeding steps, like the lethality of the exposed persons, their duration of stay in the hazardous zones, the probability of the event and so on. It follows the procedure generally outlined in figure 2. The results are the perceived collective risk of the investigated explosion event and the individual risks of the exposed persons. These two risk values are the input for the risk assessment and hence the bottom line of the risk analysis.

3. SOME PRACTICAL ASPECTS

As explained above, a risk analysis is a detailed, individual investigation of a potentially hazardous situation. Therefore, also detailed information about the storage considered is needed, like drawings of the facility showing layout, construction and special safety mesaures as for example the Klotz-device or fire extinguishing systems. All this, together with the regulation TLM 75, containing the necessary models for each step, makes a successful risk analysis only.

Further, no risk analysis should be made without a detailed survey of the actual site by the analyst. Experience shows, that there are nearly always differences between the construction drawings and the real building, especially if it is an old one, and that maps of the surrounding are never up-to-date is nothing new.

Another thing which has to be mentioned is, that performing a risk analysis is a sophisticated task. Therefore, specially educated personnel is needed. Moreover, a risk analysis can be rather time-consuming depending on the type of storage and urbanization of the surroundings.

4. SOFTWARE TOOLS

As a risk analysis can take a lot of time, already 15 years ago the first computer programs were written to support this work. These programs were running on programmable pocket calculaters. Later, a software package was developed on a "hp 9845" machine for the entire risk analysis. This program has graphical capabilities and is still in use today. As an example, figure 9 shows a typical output of the endangered objects in the surroundings of an underground magazine, whereas figure 10 shows the collective risk function for a storage according to the stored ammount of ammunition.

As the hardware support for this machine is running out, development has started for an entirely new integrated software package which contains not only the risk calculation modul, but also modules for the storing management of the entire Swiss magazine system. However, a new version of the risk analysis program is already available. It is written in FORTRAN and therefore portable, and runs on a PC with an 386 processor.

5. FINAL REMARKS

Today, Switzerland has almost 20 years of experience with risk analysis for ammunition storages. So far, on nearly 80% of all magazines a risk analysis has been performed. The experience has shown, that the procedure for the quantitative risk analysis, as we use it, is feasible and that the costs compared to the savings due to the much better use of the storing space are nearly neglectable [lit. 5].

Also the developments in other countries in the field of ammunition safety make us believe, that Switzerland has taken the right way.

At the end of this paper, it should be mentioned, that the presented general procedure for a quantitative risk analysis can not only be applied for ammunition storages but also for other activities like ammunition fabrication, transport of dangerous goods or other hazardous operations. Of course, the detail procedure and the data would have to be adapted.

REFERENCES

[Ref. 1] Schweizerische Armee
Technische Vorschriften für die Lagerung von Munition (TLM 75)
(Technical Regulations for the Storage of Ammunition)

Part 1: General Principles
Part 2: Safety Assessment
Part 3: Planning and Construction of Magazines
Part 4: Storing of Ammunition
Part 5: Storing of Ammunition by the Troops

[Ref. 2] Swiss Army / Chief of General Staff
Directives Concerning the Safety of the Handling of Ammunition and Explosives by the Military Forces and the Military Administration (WSUME)
March 25, 1991

[Ref. 3] A. F. Bienz, P. O. Kummer / Bienz, Kummer & Partner Ltd.
How the Safety of the Ammunition and Explosives Storages and Handling is Managed in Switzerland
Part I: Safety Concept, Regulations and Organisation
Paper presented at the 25th Department of Defense Explosives Safety Seminar at Anaheim/Los Angeles, USA, 18-20 August, 1992

[Ref. 4] Swiss Federal Buildings Office / Engineering Division
Model Tests for Above-Ground Magazines
Reports:
B 952-2, Test Layout and Test Program
B 952-3, Test Data and Photo Documentation, Aug. 1979
B 952-4, Data Evaluation and Summary, March 1980

[Ref. 4] Swiss Federal Buildings Office / Engineering Division
Model Tests for Shallow-Buried Magazines
Reports:
B 726-1, Test Layout and Test program, May 1976
B 726-2, Test Data and Photo Documentation, June 1976
B 726-6, Data Evaluation and Summary, November 1976

[Ref. 5] Swiss Federal Buildings Office / Engineering Division
Comparison Between the NATO Safety Principles and the Swiss Regulations for the Safe Storage of Ammunition and Explosives in Above-Ground Magazines
TM 3273-2, January 1987

How the Safety of the Ammunition and Explosives Storage and Handling is Managed in Switzerland

Part 2:

Risk Analysis of Ammunition Magazines

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on behalf of the Swiss Defence Technology and Procurement Agency

Swiss Safety Assessment Concept

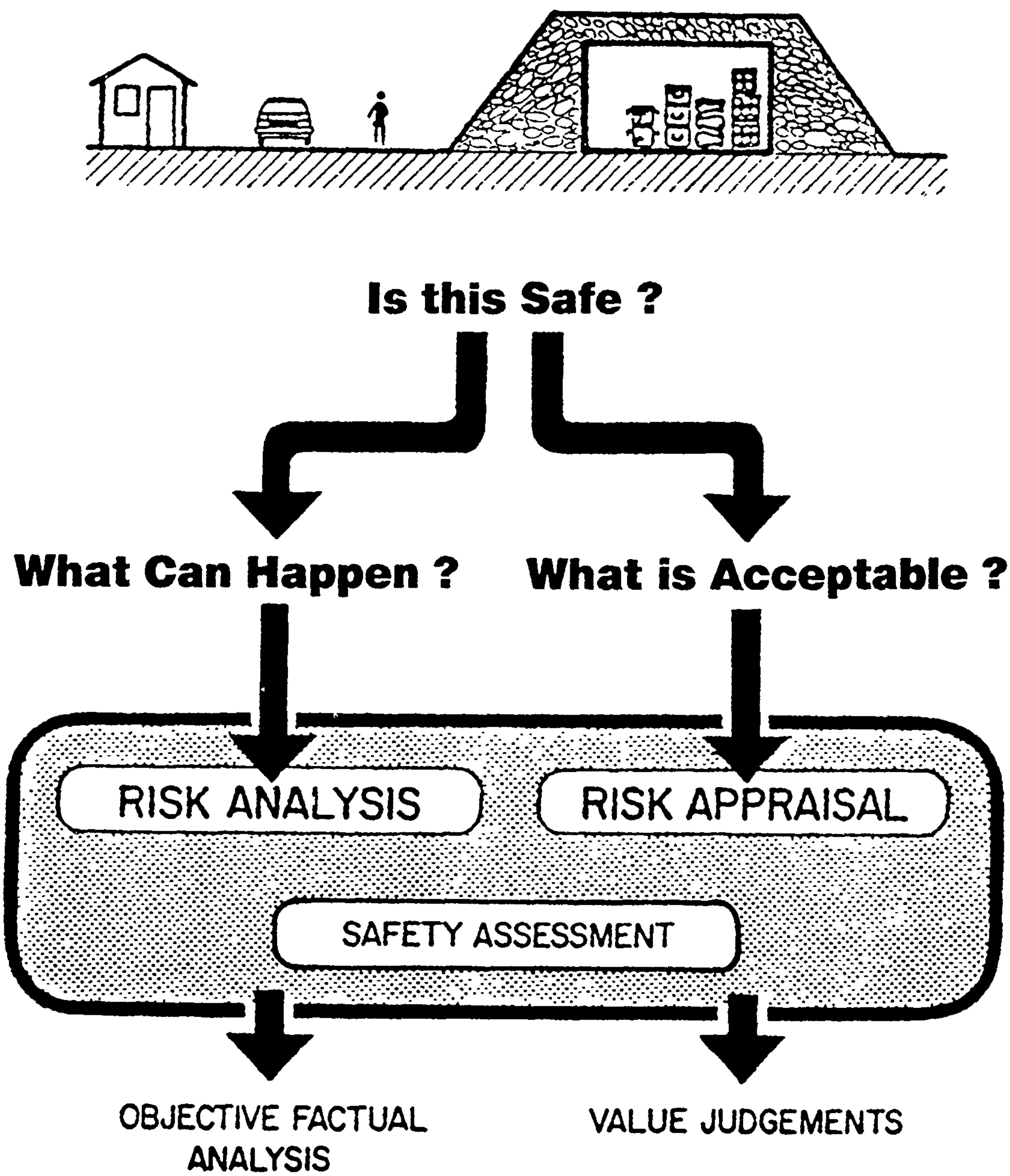
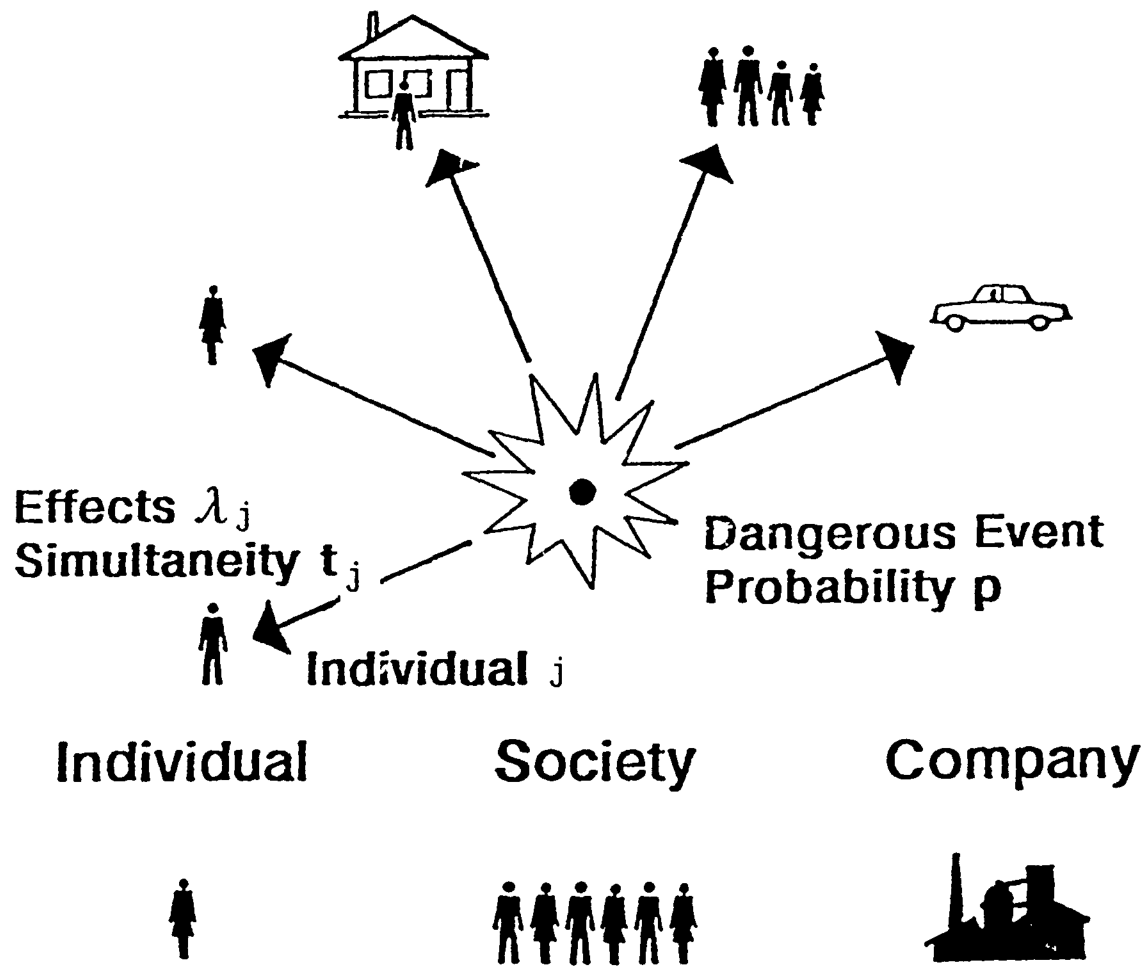


Figure 1

Definition of Risk

Risk = Probability x Consequences [1)]



Individual Risk	Real Collective Risk	Perceived Collective Risk
$r_j = p \cdot \lambda_j \cdot t_j$	$R_r = \Sigma\, p \cdot \lambda_j \cdot t_j$	$R_p = \varphi \cdot R_r$ [1)]

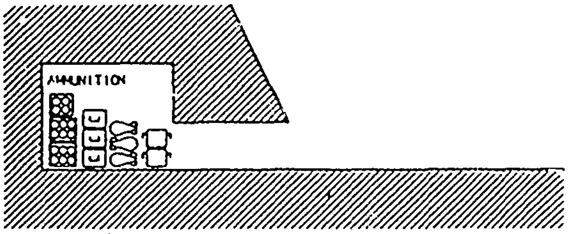
[1] Simplified

φ = Aversion

Figure 2

General Steps

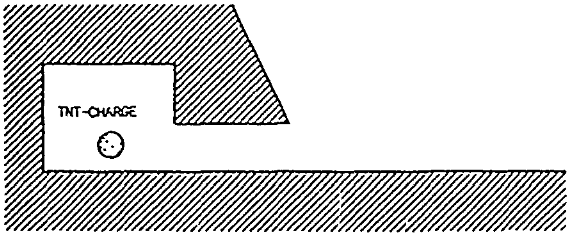
Risk Analysis of Ammunition Storage



Event Analysis

Which explosion events are possible? size? type? place? probability?

eg Which is a characteristic equivalent TNT-charge?

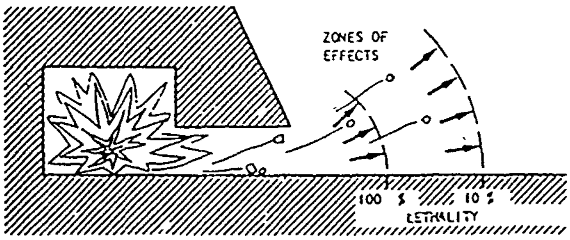


Effect Analysis

Which effects are caused by the characteristic charge?

What is the intensity of the dangerous effects for different types of objects?

How large are the endangered zones?



Exposure Analysis

Which objects are endangered in a specific situation?

What are the consequences of an explosion depending on the time at which the explosion occurs?

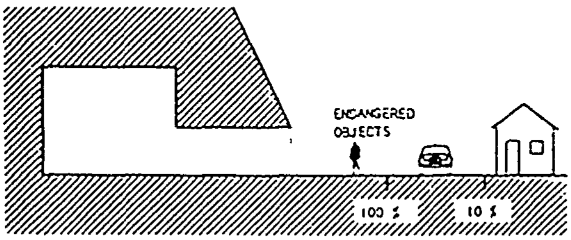


Figure 3

Event Probability

$$p = A + B \bullet X$$

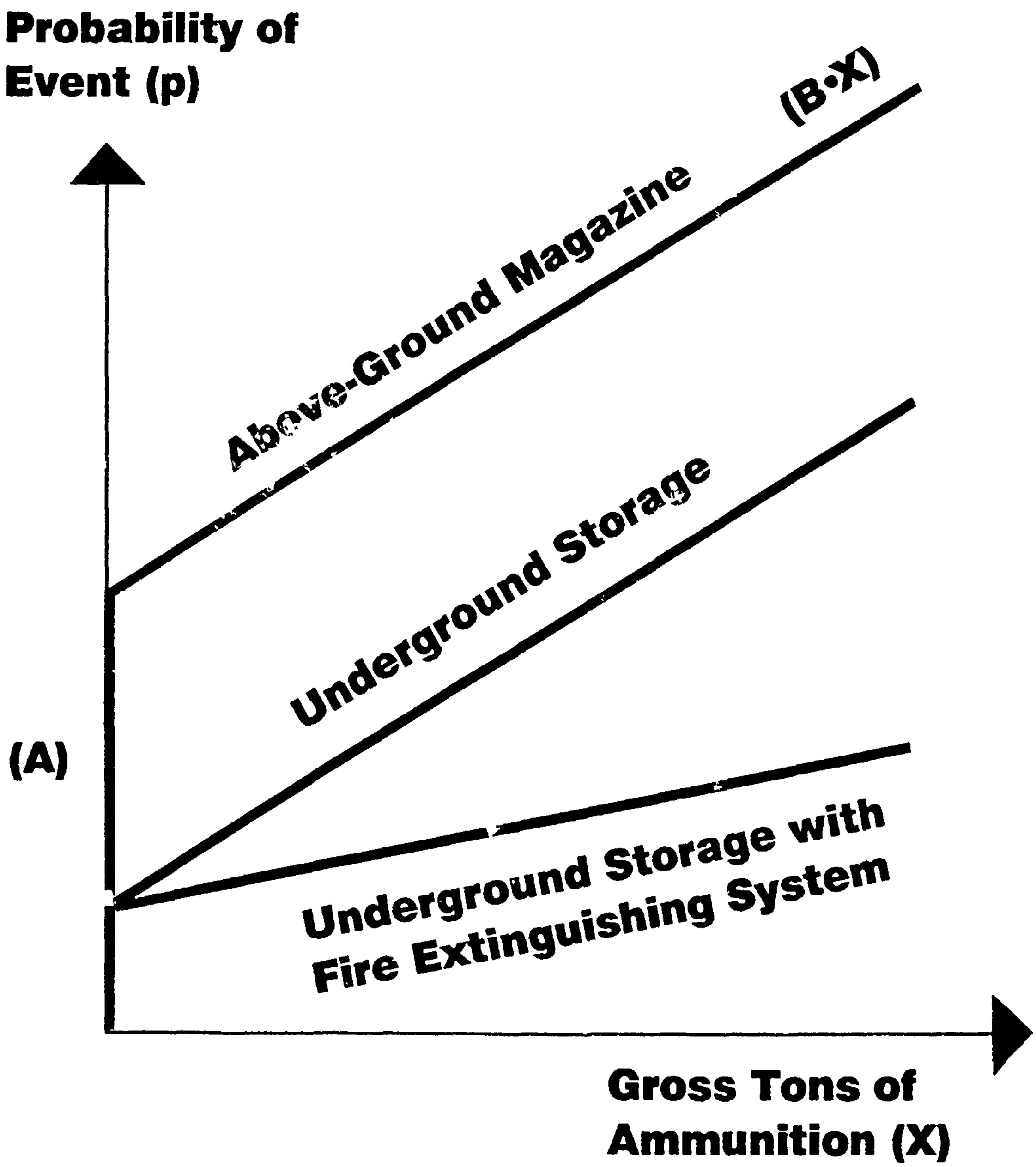
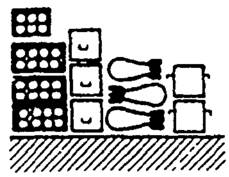


Figure 4

Size of Event

Actual Stored Ammunition



Representative TNT Quantity per Item
Dependant on :

- **Type of Storage**
- **Type of Ammunition Mixture**

Representative Event

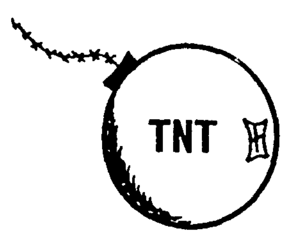


Figure 5

Explosion Effects

Example : Underground Magazine

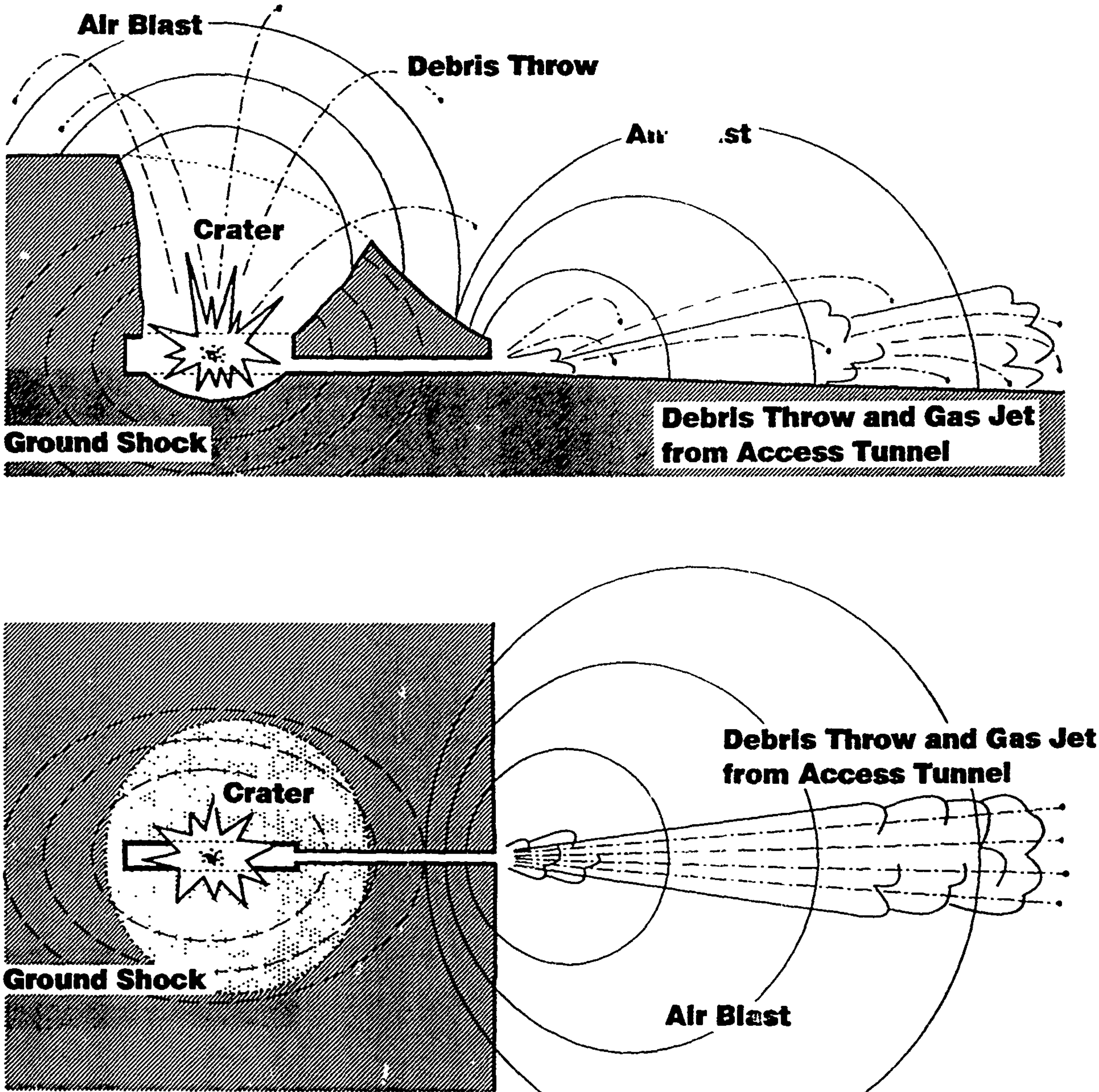


Figure 6

Effect Diagram

Example : Spreading of Air Blast
from Above-Ground Magazine

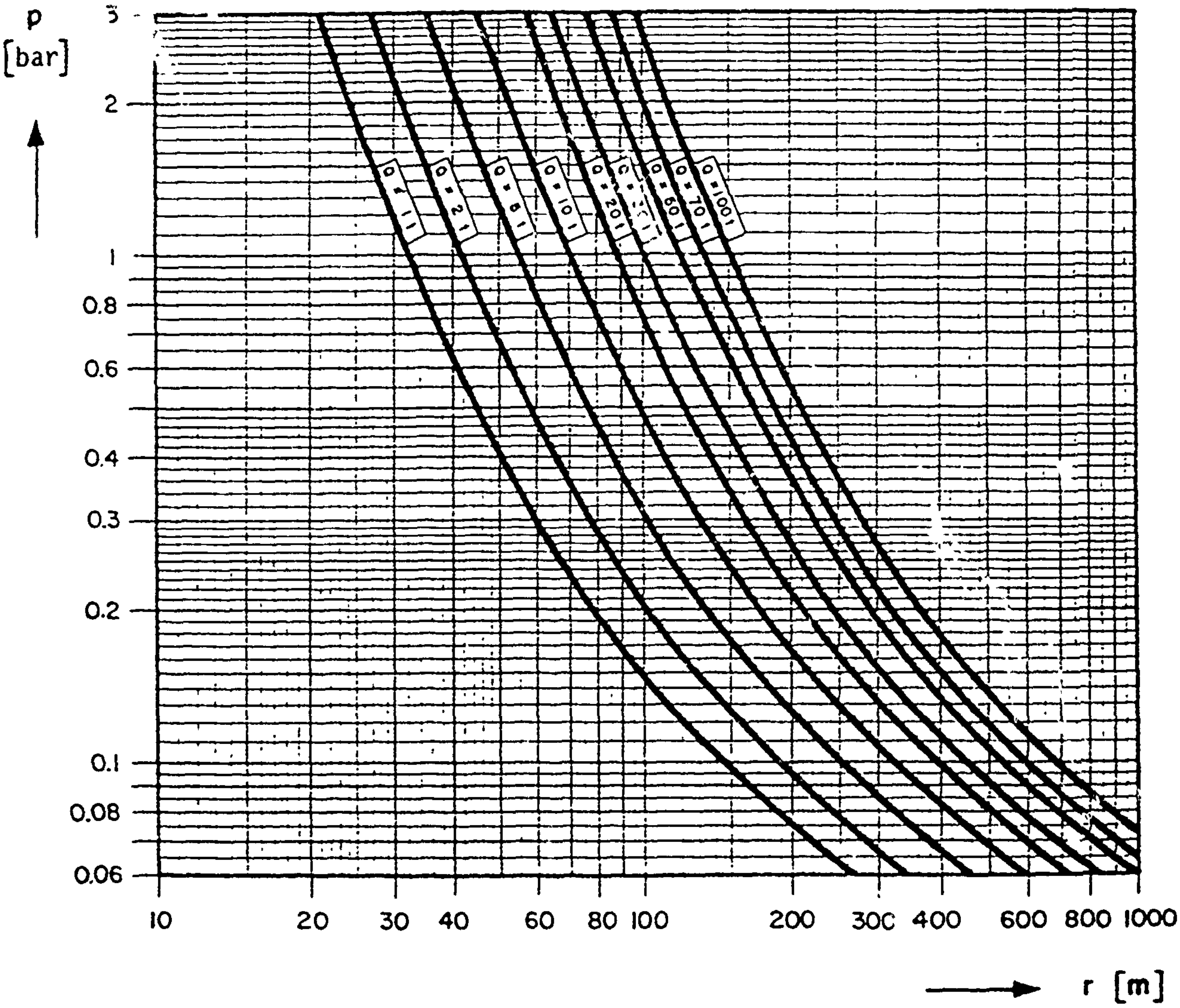


Figure 7

Exposure Analysis

Example of Analysis of Situations

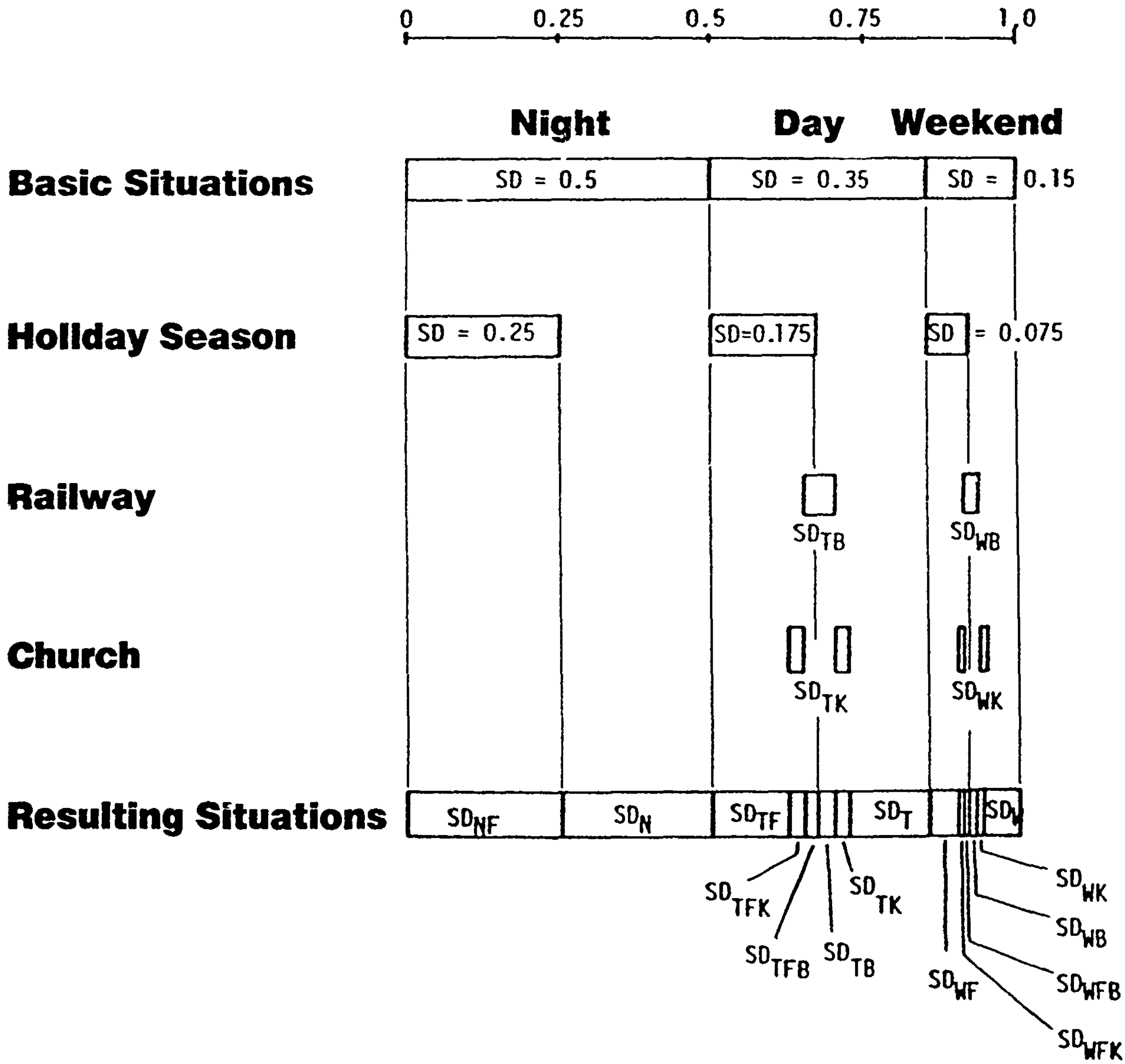


Figure 8

Hazardous Situation

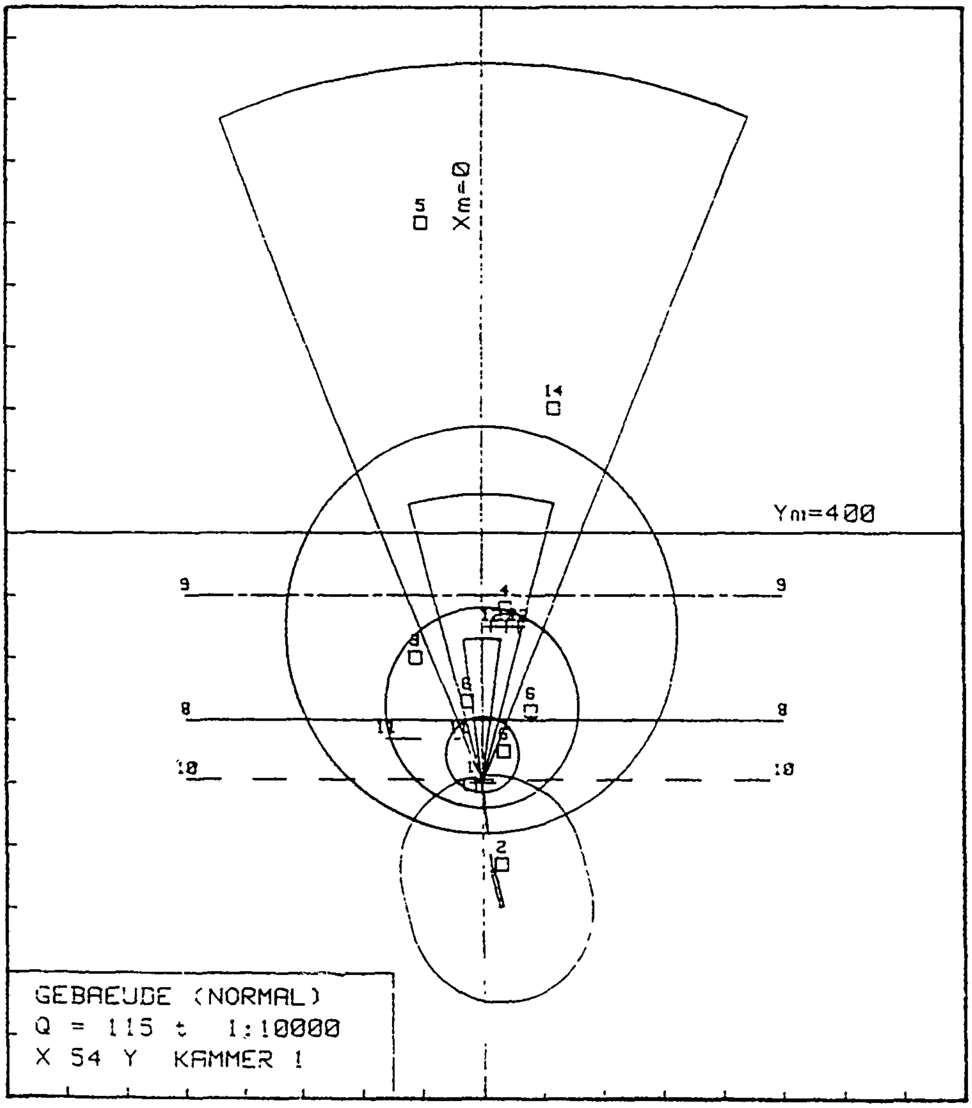


Figure 9

Risk Function

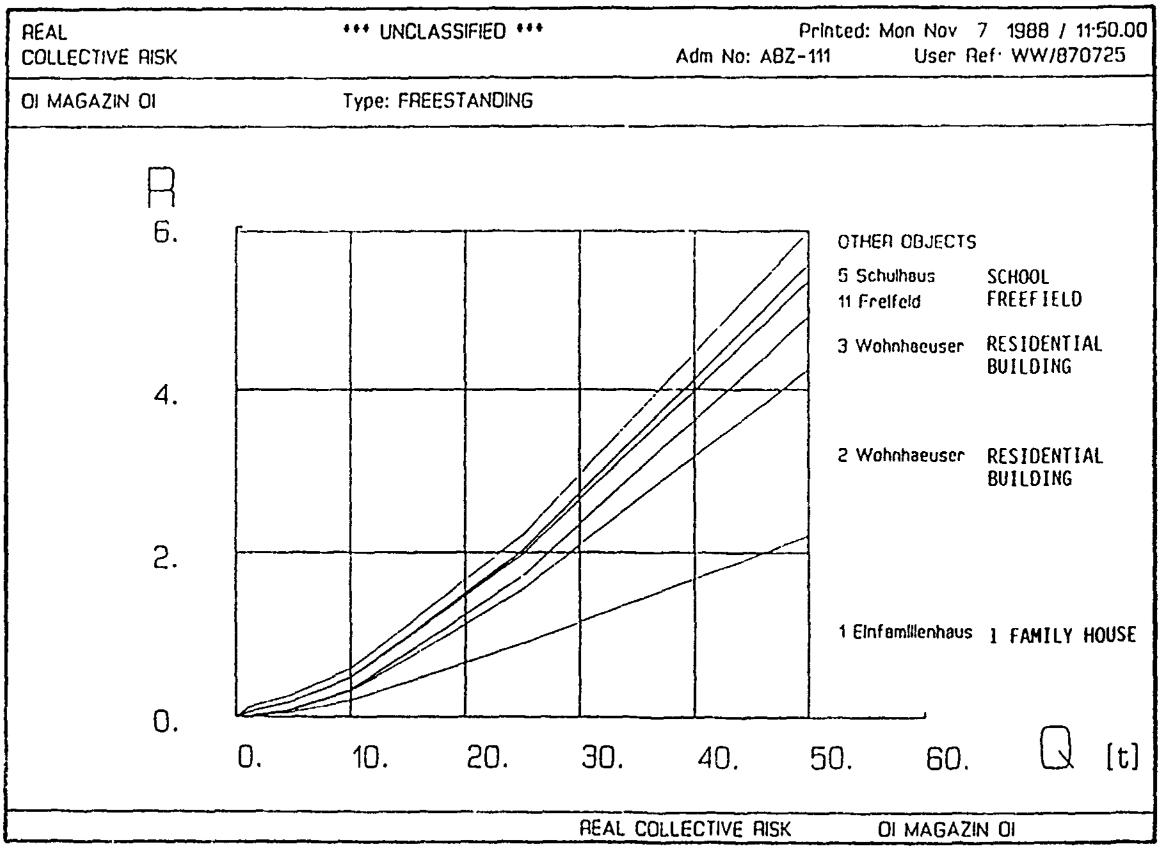


Figure 10

Experience

Switzerland : 20 Years of Experience

Advantages and Additional Benefits

- Real Hazard Known
- More Flexible
- Cost - Effective
- Better Readiness
- Better Protection

Figure 11

U.S. Army Corps
of Engineers
Huntsville Division

EXPLOSIVE ORDNANCE ENGINEERING
MCX AND DESIGN CENTER

Department of Defense
Explosive Safety Board
(DDESB)
Safety Seminar
August 18-20, 1992

CHEMICAL WARFARE MATERIEL (CWM)
Hazardous Waste or Ordnance? When Does It Matter? Who Is In Charge?

Presented by: MARGARET P. WALLS J.D.
US Army Corps of Engineers
Huntsville Division
Office of Counsel

INTRODUCTION

A problem has arisen within the Army Corps of Engineers on the above issue. There are two written legal opinions within the Army, one from the Army Material Command and one from the Office of General Counsel. These opinions state that chemical munitions recovered from formerly-used defense sites are hazardous waste and therefore, all RCRA emergency provisions should be followed in Emergency Ordnance Disposal actions. This paper will highlight why this classification causes conflicts to arise when dealing with the chemical materiel, and how some environmental programs are and could be impacted in the future. This is a Department of Defense issue that needs to be reconciled now.

SOME DEFINITIONS

Army Regulation 50-6 defines chemical surety materiel as: Chemical agents and their associated weapon systems, or storage and shipping containers that are either adopted or being considered for military use. Chemical surety materiel is categorized as follows:

a. Category I -- bulk nerve agents stored in 1-ton containers, neat rounds (nerve and non-nerve), mines, rockets and bombs, less those items described in categories II, IV, and V below.

b. Category II -- chemical surety materiel in an approved demilitarization program and/or recovered from Army installations or the civilian community.

c. Category III -- binary munitions with both components.

d. Category IV -- bulk non-nerve agents stored in 1-ton containers, except that approved for demilitarization, or RDTE [research, development, test, and evaluation], surveillance or training.

e. Category V -- chemical surety materiel used for authorized RDTE projects, specific surveillance programs, intelligence evaluation or scheduled training programs. Chemicals not listed as chemical surety materiel in appendix C are not covered by this regulation.

WHY IS THIS A PROBLEM?

The Defense Environmental Restoration Program was established under 10 U.S.C. 2701 et seq. That program addresses the remediation of sites that have been contaminated by the Department of Defense, both current (active) sites and formerly-used sites (FUDS). The Corps of Engineers has been designated as the agency to investigate and identify FUDS where contamination exists. The three types of contamination that might be present are: (1) unsafe debris; (2) hazardous and toxic waste (HTW); and (3) other contamination such as unexploded ordnance and explosive waste (OEW). Within the Corps, the Huntsville Division has been designated the Mandatory Center of Expertise (MCE) to deal with OEW problems. The Missouri River Division (MRD) has been designated the MCE to deal with HTW.

Under section 300.120 of the National Contingency Plan (NCP), the Environmental Protection Agency (EPA) and the United States Coast Guard are the response authorities for HTW contamination and oil discharges. The Department of Defense (DOD) has been designated the removal response authority for incidents involving DOD military weapons and munitions or weapons and munitions under the jurisdiction, custody or control of DOD. By classifying CWM as hazardous waste, the response authority is not DOD. However, under Army regulations, only the Technical Escort Unit (TEU) within the Army Material Command (AMC) can transport and/or dispose of chemical agents/munitions. Licensed HTW contractors are not familiar with the properties of CWM and have not been trained in the proper precautions that need to be taken when dealing with chemical agents/munitions.

Under the various AR's dealing with chemical agents/munitions, there are particular security precautions which must be followed, such as double fencing, and 24-hour guards. These chemical agents are lethal substances. The fact that some of them have been buried for 40 years have

not changed that characteristic. The potential for these to fall into the hands of a terrorist is real. This issue needs to be settled before that situation occurs.

RECOMMENDED PROCEDURES

Chemical agents/munitions are by their very nature hazardous substances. They are lethal. This is the reason that one agency, TEU, has been designated by DOD to handle this stuff. No one wants Mr. HTW Contractor to even be in the vicinity when this materiel is neutralized, treated, transported, etc. Handling this materiel requires special knowledge that only TEU possesses.

If we can classify discovered chemical agents/munitions as ordnance, then DOD will be the proper removal response authority and TEU can come in and do their job. The Army Regulations will control the procedures. TEU can conduct its response as an emergency disposal, which is defined in AR 50-6 as: Immediate transportation and disposal of chemical agents/munitions when the senior explosive ordnance disposal person determines the health or safety of any person is clearly endangered. Emergency disposal operations may be conducted free of the prior approval restrictions imposed by Public Laws 91-120, 91-121, 91-441 and this regulation. Explosive ordnance disposal is the detection, identification, field evaluation, rendering safe, recovery and final disposal of unexploded explosive ordnance or munitions chemical agents.

Why would this be the recommend approach? The biggest concern with discovered chemical agents/munitions is the safety hazard it poses in an uncontrolled situation. If a container ruptured and was in a populated area, there could be a death. This is not an acceptable risk. When chemical agents/munitions are "discovered", the TEU should be able to come in, assess the situation, neutralize on site, or transport to the nearest installation that is authorized to accept CWM.

If CWM is discovered, and because it has been buried, it must be classified as HTW, there are certain procedures that come into play if it needs to be transported off site. This is where the biggest conflicts arise within the regulatory arena. Obtaining a Department of Transportation

permit to transport HTW is not a problem. The problem is having a destination that can accept it. There are facilities throughout the country that are permitted to accept HTW for storage or disposal. However, none of these HTW facilities have permits in place that can accept chemical agents/munitions, because these are ordnance items, not normal HTW products.

There are 8 U.S. Army installations with chemical surety missions. Why couldn't the discovered chemical agents/munitions be taken to these installations? The reason is that once they are classified on site as HTW and manifested as such on the DOT transportation permit, the installations are not licensed to receive HTW. The installation commander would be violating the RCRA permit issued to the installation.

Safety should be the priority when dealing with chemical agents/munitions. Because of the nature of CWM, a special unit has been designed to deal with it. The TEU personnel are individuals technically qualified and properly equipped to accompany designated materiel which requires a high degree of safety and security during shipment. (CWM is to be transported by air).

The goal when CWM is discovered it to neutralize it. This is defined as the act of altering the chemical, physical, and toxicological properties to render the chemical agent ineffective for use as intended. Neutralization is one method of demilitarization of these agents/munitions. Demilitarization is the mutilation, destruction, or neutralization of chemical surety materiel, rendering it harmless and ineffectual for military purposes.

One of the rationales given in the two legal opinions mentioned in the introduction is that this is waste because it has been buried. The implication being that DOD could never anticipate using this again. However, before DOD can abandon chemical agents/munitions, the regulations clearly state that they must be demilitarized. Perhaps forty years ago the need to demilitarized existed, but the knowledge did not. That has changed. Also, we are required by the Defense Environmental Restoration Program to seek out and clean up wastes we left behind, and one of the three categories of waste is ordnance.

One of the other rationales for wanting to classify chemical agents/munitions as waste is that because the removal of same is a planned action that an emergency does not exist. It would seem that the contrary would apply here. If CWM is discovered, the removal of that must be carefully planned due to the nature of the materiel. Some of these materiels are lethal in small quantities. There are no warning signals for some agents, and no antidotes. If careful planning were not done, a disaster could be the result.

SUMMARY

This may not seem like an issue that could have far reaching effects. However, under the DERP-FUDS, there are potentially 200 sites that could have buried CWM. If it is classified as HTW, there are problems with who can remove it and where can you take it once it is removed. If classified as OEW, the Army has procedures and safeguards in place that can swiftly, safely and efficiently handle the problem. The only step the Army needs to take is to have the installations with CSM missions amend their RCRA permits, so that this discovered CSM, once at their installations and properly classified, will not violate their reporting requirements.

For existing chemical stockpiles, or even for CWM that is discovered on active installations, these problems do not arise. The CWM is treated as being actively owned and controlled by the DOD. This problem is manifested when the CWM is discovered buried at sites formerly used by the DOD. It would seem like the logical conclusion would be to treat the item the same regardless of where it is located. A bomb is a bomb. Chemical agents/munitions are just as lethal outside of the installation's fence as they are inside the fence. The concern should be to remove or demilitarize the discovered agents/munitions as quickly and safely as possible, minimizing any threat to the safety of persons or surrounding environment. The Army regulations allow this to happen. Since DOD is the removal response authority for weapons and munitions under the NCP, we should let them handle these situations accordingly.

CHEMICAL AGENTS/MUNITIONS

	IF HTW:	IF OEW:
Response authority:	EPA	DOD
Permits required:		
For transport	DOT	None
For storage >90 days	RCRA	None
Security	none	maybe
On-site disposal	None	None
Off-site disposal	RCRA	None*

*The agents/munitions would be transported to an installation with chemical surety mission. Upon receipt, the items would be classified and the installation would be responsible for any permit requirements.

CHEMICAL AGENTS/MUNITIONS

Where can it be taken?

If classified HTW -- UNKNOWN*

If classified OEW -- an installation with CSM mission.

*Disposal of HTW must be at landfill or disposal facility licensed for that particular type of waste. The author of this paper does not know of any HTW disposal facility licensed to handle undiluted CSM. Once CSM has been demilitarized into non-lethal components, there are probably facilities that can handle that non-lethal waste.

PROPOSED OR RECOMMENDED RESOLUTION

1. Have on-scene coordinator (TEU) recognize CSM as OEW.

2. Have the U.S. Army installations with a CSM mission amend their RCRA permits to allow them to accept CSM discovered in the civilian community that cannot be taken care of on-site.

3. If it cannot be neutralized or remediated on-site, TEU should transport to nearest installation with CSM mission.

4. Once safely transported to an installation, all permit requirements, etc., will be satisfied by installation.

MITIGATIVE FEATURES FOR EXPLOSIVE CONTAINMENT ON THE CHEMICAL STOCKPILE DISPOSAL PROGRAM

BY
BOYCE L. ROSS, P.E.[1]

ABSTRACT

Public Law 99-145 mandated that the Army dispose of the United States inventory of obsolete and deteriorating chemical weapons in the safest and most environmentally acceptable manner. The Chemical Stockpile Disposal Program (CSDP) was created by the Department of Defense (DOD) to accomplish this mission. The CSDP encompasses reconfiguration, transportation, disassembly, and incineration of deteriorated chemical munitions utilizing state-of-the-art facilities and techniques. The disposal of these munition must be accomplished in strict accordance with all current environmental regulations and under vast public scrutiny. The CSDP has implemented many mitigative measures in order to increase safety and to alleviate public concern in the event of an accidental detonation within these facilities.

PROGRAM BACKGROUND

Chemical weapons have been in existence since World War I. The first chemical agents consisted of blister agents (vesicants) commonly known as mustard and lewisite gases. Later, nerve agent VX, Sarin (GB), and Tabun (GA) were developed. Chemical agents in the current inventory are from 24 to 47 years old. These chemical agents are loaded into a multitude of delivery systems such as M55 rockets, mortars, projectiles, land mines, and bombs. Approximately 60 percent of the inventory is contained in bulk ton containers. Table 1 shows the agent types and munition delivery configurations within the United States inventory. The United States has eight sites within the continental United States (CONUS) which store chemical munitions and bulk containers. Six of these sites, Tooele Army Depot, Tooele, Utah; Anniston Army Depot, Anniston, Alabama; Umatilla Depot Activity, Umatilla, Oregon; Pine Bluff Arsenal, Pine Bluff, Arkansas; Pueblo Depot Activity, Pueblo, Colorado; and Lexington-Bluegrass Army Depot, Lexington, Kentucky, contain explosively configured chemical munitions. The remaining two sites, Newport Army Ammunition Plant, Newport, Indiana, and Aberdeen Proving Ground, Aberdeen, Maryland, store only bulk containers. Figure 1 shows the United States storage locations and the quantity of munitions by weight of chemical weapons stored on these sites as a percentage of the total inventory.

---

[1] Boyce L. Ross, P.E., Chemical Demilitarization Directorate, U.S. Army Engineer Division, Huntsville

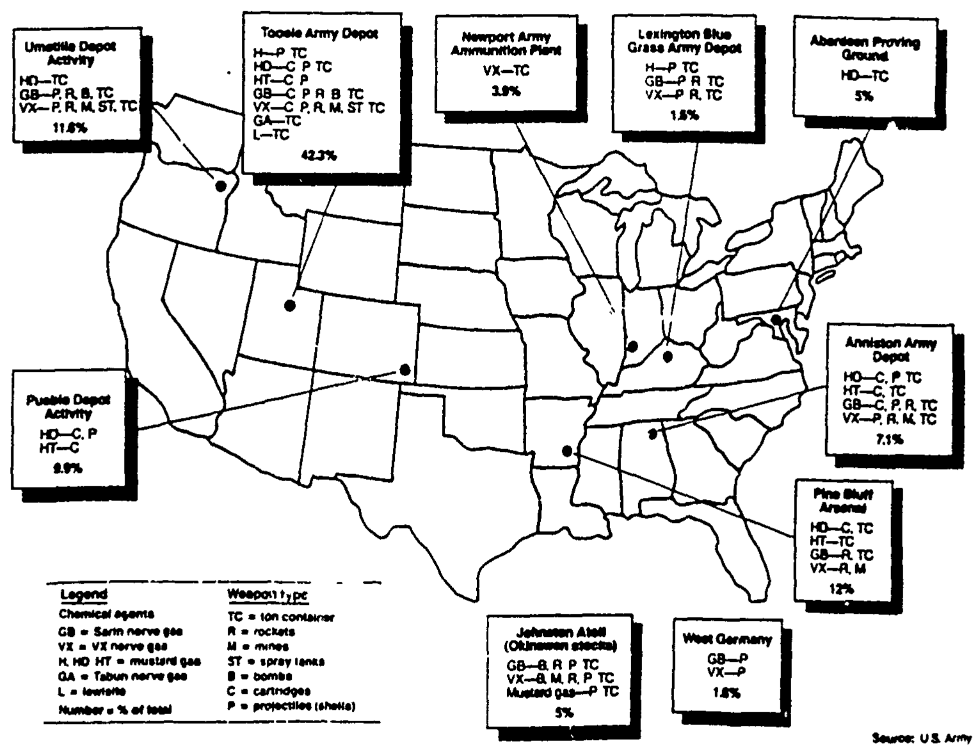
Table 1. Chemical munitions stored in the continental U.S.

Chemical munitions/agent	APG	ANAD	LBAD	NAAP	PBA	PUDA	TEAD[a]	UMDA
Mustard agent (H, HD, or HT)								
105-mm projectile (HD)		X				X		
155-mm projectile (H,HD)		X	X			X	X	
4.2-in. mortar (HD,HT)		X				X	X	
Ton container (HD)	X	X			X	X[b]	X	X
Ton container (HT)					X			
Agent GB								
105-mm projectile		X					X	
155-mm projectile		X					X	X
8-in. projectile		X	X				X	X
M55 rocket		X	X		X		X	X
500-lb bomb								X
750-lb bomb							X	X
Weteye bomb							X	
Ton container		X[b]	X[b]		X[b]		X	X[b]
Agent VX								
155-mm projectile		X	X				X	X
8-in. projectile							X	X
M55 rocket		X	X		X		X	X
M23 land mine		X			X		X	X
Spray tank							X	X
Ton container				X				X[b]

[a]Small quantities of Lewisite (L) and tabun (GA) are stored in ton containers at TEAD.
[b]Small quantities of agent drained as part of the DATS/M55 assessment.

Figure 1. U.S. chemical weapons storage sites

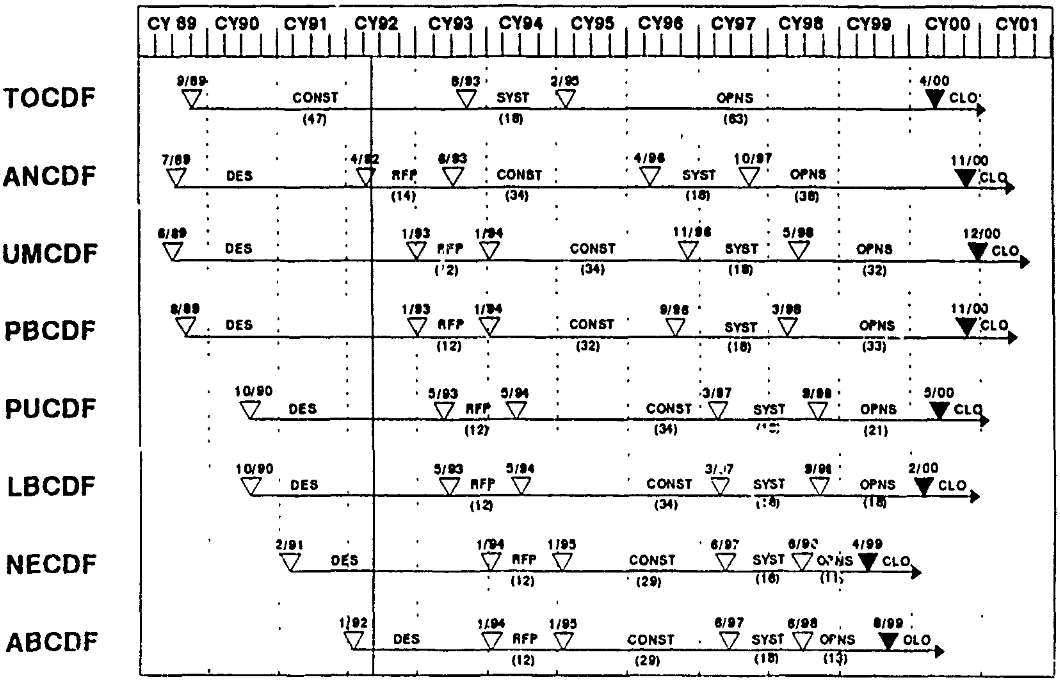
Chemical weapons are stored at eight U.S. sites and two sites outside continental U.S.



Program Implementation History

The United States commitment to destruction of chemical weapons began in 1975 with the signing of the Geneva Protocol. In 1985, Congress passed Public Law 99-145, the Defense Authorization Act of 1986, which mandated the destruction of the entire United States inventory of obsolete and unserviceable chemical weapons by 1994. In June of 1990, the United States and the former Soviet Union signed a bilateral agreement to destroy their entire stockpiles of chemical weapons. This agreement, although never ratified, stated that 50 percent of the United States stockpile of chemical weapons would be destroyed by December 1999, followed by all but 5,000 metric tons by May 2002. Thus, Public Law 99-145 was amended to direct the DOD to complete destruction of the entire United States inventory by September 1999. The current programmatic schedule is shown in Figure 2.

Figure 2. Chemical Demilitarization Program implementation schedules



In order to execute this mission, the Secretary of Defense created an organization now known as the Program Manger for Chemical Demilitarization (PMCD), headquartered in Edgewood, Maryland. The PMCD falls under the direct command and control of the Assistant Secretary of the Army (Installations, Logistics, and Environment). The U.S. Army Corps of Engineers serves as the Life Cycle Project Manager and the PMCD Facility Design and Construction Agent for the CSDP. The U.S. Armament and Material Command (AMCCOM) acts as the contracting agent for the Army.

DESTRUCTION TECHNOLOGY

Until 1969, the Army disposed of chemical weapons by techniques such as open-pit burning, evaporation, burial, and ocean dumping. During the early 1970's, the DOD studied chemical weapon disposal technologies such as chemical neutralization and incineration. All of the technologies studied eventually resulted in some component of the chemical weapon being incinerated. This, along with other problems such as the deterioration of the GB filled M55 rockets, led the Army to focus on incineration as the technology for destruction of chemical weapons. During the late 1970's, the Army created the Chemical Agent Munitions Disposal System (CAMDS) located in Tooele, Utah. This facility still serves as the Army test and evaluation location for much of the specialized demilitarization process currently being utilized in the CSDP designs.

The current Army demilitarization technology consists of a reverse assembly process whereby live chemical munitions are brought to the Munitions Demilitarization Building (MDB) and remotely dismantled within explosive containment rooms (ECR's) by highly specialized robotic equipment. The MDB is operated under a cascading negative pressure ventilation system with respect to atmospheric pressure. This ventilation system is the primary means by which containment of chemical agent vapors resulting from the disassembly process is maintained. Once dismantled, components of the munitions are incinerated in one of four types of incinerators.

The demilitarization process begins by loading munitions into highly specialized on-site containers (ONC's) within the chemical weapons storage area. The use of the ONC evolved from public concern over the ability of the Army to safely transport live chemical munitions, even over relatively short distances (a few miles). These containers can be compared to transport containers used to convey nuclear materials in that they must survive drop, crash, fire, and pressure tests and maintain their integrity as a containment vessel.

Once loaded into the ONC, munitions or containers are transported into the adjacent Chemical Stockpile Disposal Facility site. The ONC's are off-loaded at the Container Handling Building (CHB) where they are held for processing. The CHB is separated from the MDB by a 200-foot-long corridor which provides for intraline separation. When the ONC is needed for processing, it is conveyed down the corridor and raised to the second floor transition area where it is monitored for leaks, opened and unpacked. Pallets of munitions are then conveyed into

the unpack area (UPA) room where they are manually separated from the packing material (dunnage) and placed on munition conveyors for disassembly in the containment rooms. Dunnage resulting from unpack operations is conveyed down to the first floor via a lift enclosure and ram-fed into the dunnage incinerator.

Each munition type follows a disassembly process specific to the munition configuration. All energetic materials are removed from the munitions in the ECR's. Each munitions demilitarization building has two functionally identical ECR's. Once inside these rooms, explosives are separated from the munition and/or reduced in size and fed into the deactivation furnace room which is located beneath the containment rooms. Liquid nerve agent is siphoned out of munitions either in the containment room or the munitions processing bay (MPB). Agent, which is removed from the munition body or ton container, is collected in tanks within the toxic cubicle (TOX) on the first floor and incinerated in the liquid incinerator (LIC). Munitions bodies and ton containers which contain small portions of residual liquid agent after draining operations are thermally decontaminated in the metal parts furnace (MPF). The detailed description of disassembly process for each explosively configured munition are discussed below.

Rocket Processing

The M55 rocket is unique to the chemical munition stockpile in that all components are encased in a fiberglass shipping/firing tube that contains both the rocket propellant and the liquid chemical agent. A schematic of the rocket processing line is shown in Figure 3. The M55's are manually loaded onto the rocket input conveyors in the UPA. Their orientation is checked and the input blast gate to the ECR is opened. Once inside the containment room the rocket is advanced to the rocket drain station (RDS) on the rocket shear machine (RSM). The input blast gate is shut to afford containment in the event of an accidental detonation. The rocket is punched at the RDS and agent is drained into TOX. When the draining operation is complete, it is indexed into the shearing station and another rocket enters the containment rooms. Only two rockets are allowed to enter the containment room, one in the drain station and one in the shear station. At the shearing station the rocket firing tube is sheared into segments. Sheared segments fall onto a blast gate mounted on the ECR floor. This gate cycles open and the explosive burster/propellant fall onto a flapper gate. The upper gate is closed and the lower flapper gate allows the energetics to fall into the deactivation furnace system (DFS). These gates provide category I protection to personnel that may be performing maintenance or changeout of equipment in the opposite ECR. They also control feed into the furnace. They also prevent a blast in either the containment room or the furnace room below from propagating into the other room.

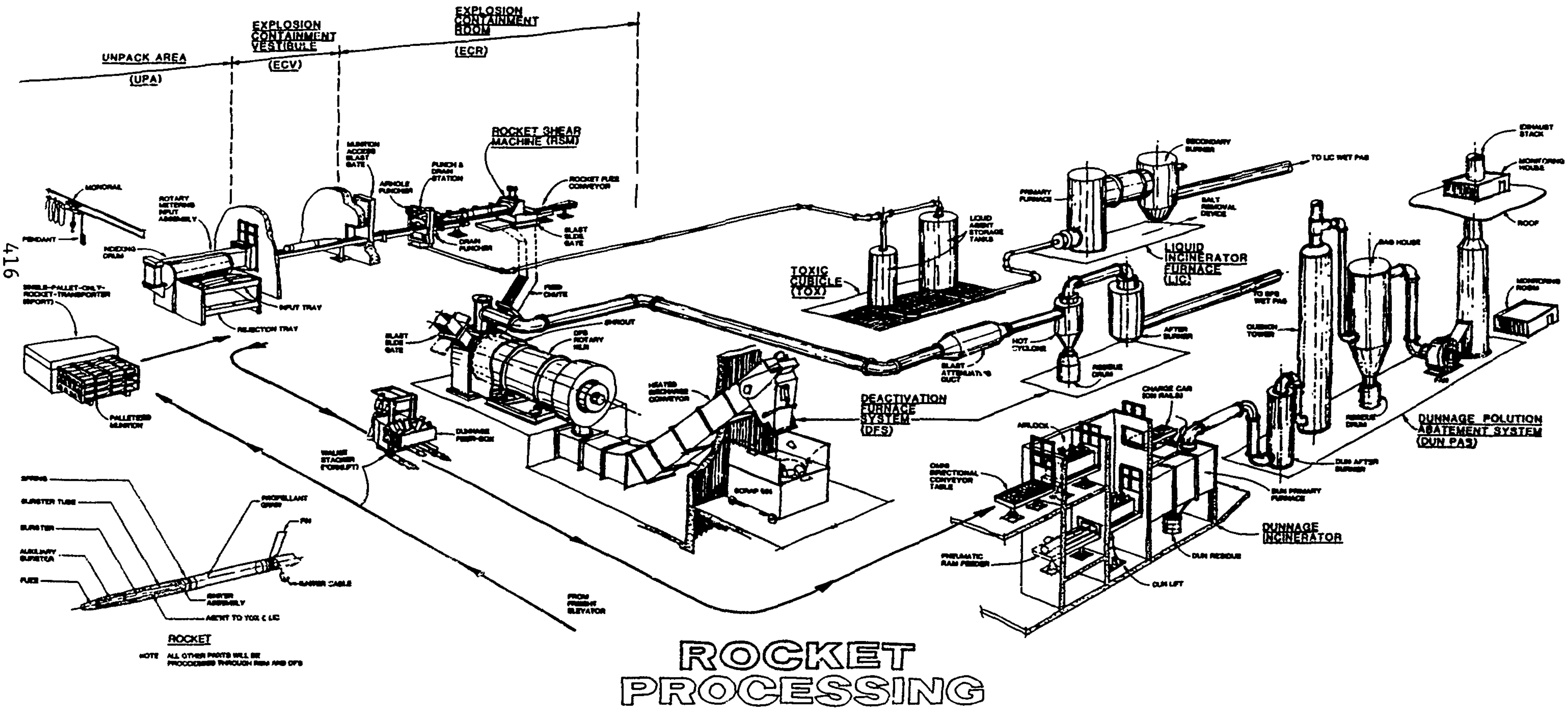


Figure 3. Rocket Processing Schematic

Mine Processing

The land mines which contain chemical agent also pose a unique problem in that they are packaged three to a drum. Between each mine is packing material which makes it difficult to detect leaks. For this reason all mines are unpacked in a glove box adjacent to the UPA and conveyed into the ECRs through the blast gate. When the first mine enters the ECR it is oriented in the first station of the mine machine for punching and draining. Once agent is drained, it is moved to the next station and a second mine enters the containment room through the blast gates. The next station removes the booster charge by pushing it from the mine and punching a hole in the charge. The booster charge is then dropped onto the upper blast gate and fed into the furnace below. The mine body with the remaining main explosive charge, burster pellet, and M48 charge are then segregated onto conveyors and fed into the furnace through the feed chute gates.

Projectile Processing

Each different type of projectile will be processed in a separate campaign. The projectile processing line is shown in Figure 4. Projectiles and mortars are loaded into the projectile/mortar rotary metering input system in the UPA and fed into the ECR's through the projectile blast gates. After entering the ECR the projectiles are conveyed to the projectile mortar disassembly machine (PMD). This machine has three stations where the lifting plug or fuse is removed and deposited onto a conveyor for incineration in the DFS. The next station removes any supplementary charge such as bursters. Depending on the burster size, some bursters will be conveyed to a burster size reduction (BSR) machine and reduced in size prior to being fed into the DFS. For all projectiles, except the 8-inch, three munitions will be in the containment room at one time. Because more than one 8-inch projectile will exceed the explosive limit of the containment room, only one 8-inch projectile is processed at a time. Once all energetics are removed from the projectile they are conveyed out of the ECR through the output blast gates and into the munitions corridor where they are loaded onto munitions trays. From there they are conveyed into the munitions processing bay (MPB) where they are punched and drained utilizing other specialized demilitarization equipment. Once punched and drained, the projectile bodies are fed into the metal parts furnace for thermal decontamination.

Other Chemical Weapon Configurations

Spray tanks, ton containers, and bombs are not explosively configured in the U.S. stockpile. The ECR's are not utilized for processing these munitions. They are instead conveyed directly to the MPB where they are punched and drained.

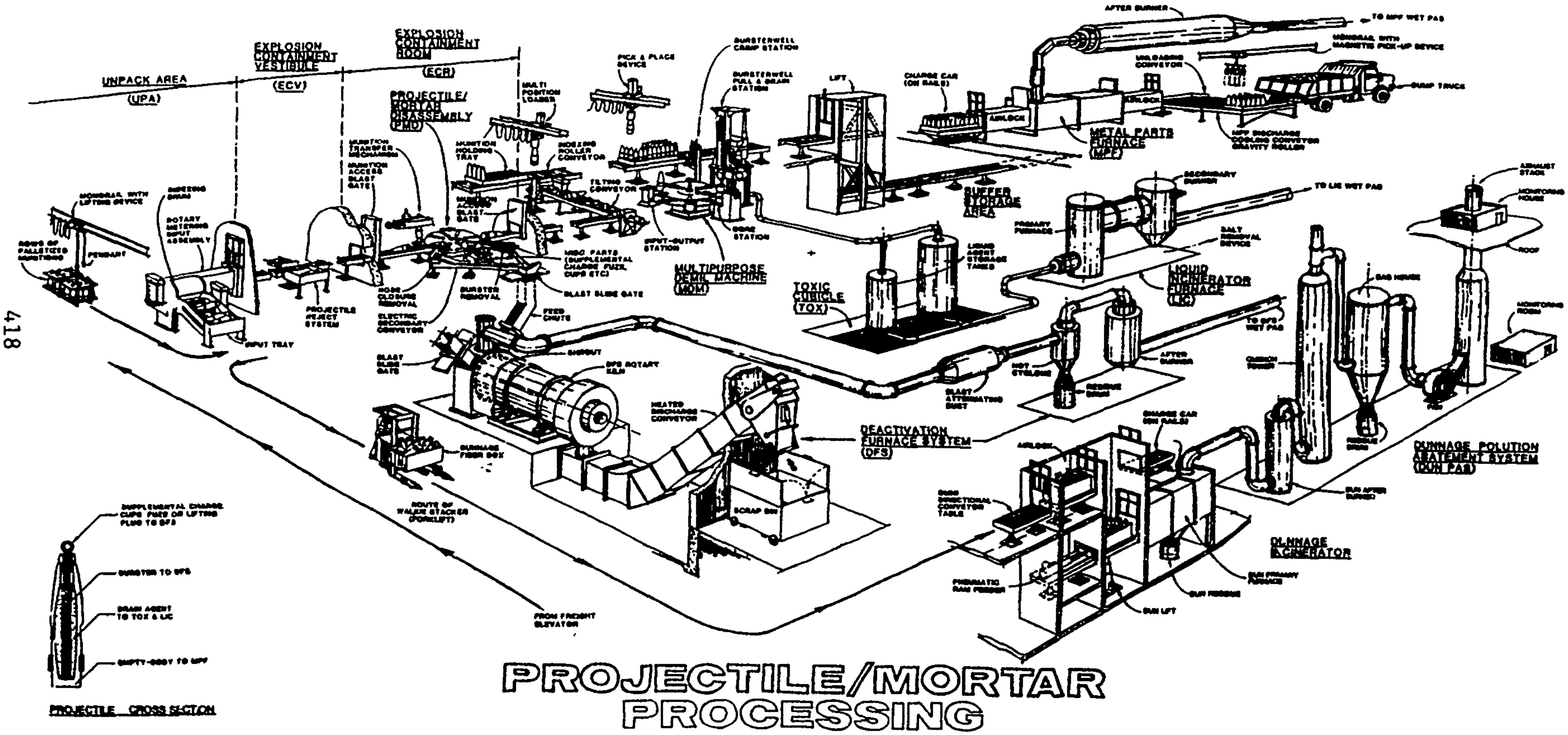


Figure 4. Projectile Processing Schematic

EXPLOSIVE CONTAINMENT

Introduction

Removal and incineration of all energetics from live chemical munitions occurs within blast containment areas in the MDB. The CSDP explosive containment areas consist of two functionally identical ECR's located on the second floor of the MDB. Incineration of all explosives occurs within the DFS located within a blast containment room on the first floor of the MDB. An isometric view of the blast containment structure is shown in Figure 5. It should be noted that only the DFS room and the ECR's are designed as blast containment rooms. The toxic cubicle room and the spent decon system (SDS) room are included on the blast containment structure foundation mat due to seismic considerations.

Functional Requirements:

Because of the hazardous operations performed on explosively configured munitions within the MDB, all personnel must be afforded category I protection from blast and fragment effects for the maximum credible event (MCE) in accordance with DOD 6055.9-std. Since separation distances are not achievable within the confines of the MDB, total containment of blast and fragmentation effects and near total vapor containment is required. Specific functional requirements for the ECR's and the DFS room are discussed individually in the following paragraphs.

Explosive Containment Rooms: Figure 6 shows a plan view of the second floor ECR area. The rocket shear machine, projectile/mortar disassembly machine, and the mine machine are located in these rooms during respective campaigns. In each ECR there are two process input conveyors and a single output conveyor, two personnel entry doors, several utility penetrations and a floor penetration for gravity feed of munition components into the DFS. Blast and fragment resistant closures are provided in each duct at the containment wall penetration. Each ECR must provide complete containment from blast and fragment effects and near total containment of the contaminated gaseous by-products escaping after an incident. Containment must be maintained until the confined gas products cool and internal pressure decays to a level where they may be processed through the ventilation system. Following the MCE, the ECR's will be reusable with minor refurbishment. The total blast environment, which the containment structure must resist, includes high pressure shock waves, quasi-static gas pressure, and primary and secondary fragments. The explosive limit of the ECR's are based upon the maximum amount of explosive present in the room during processing

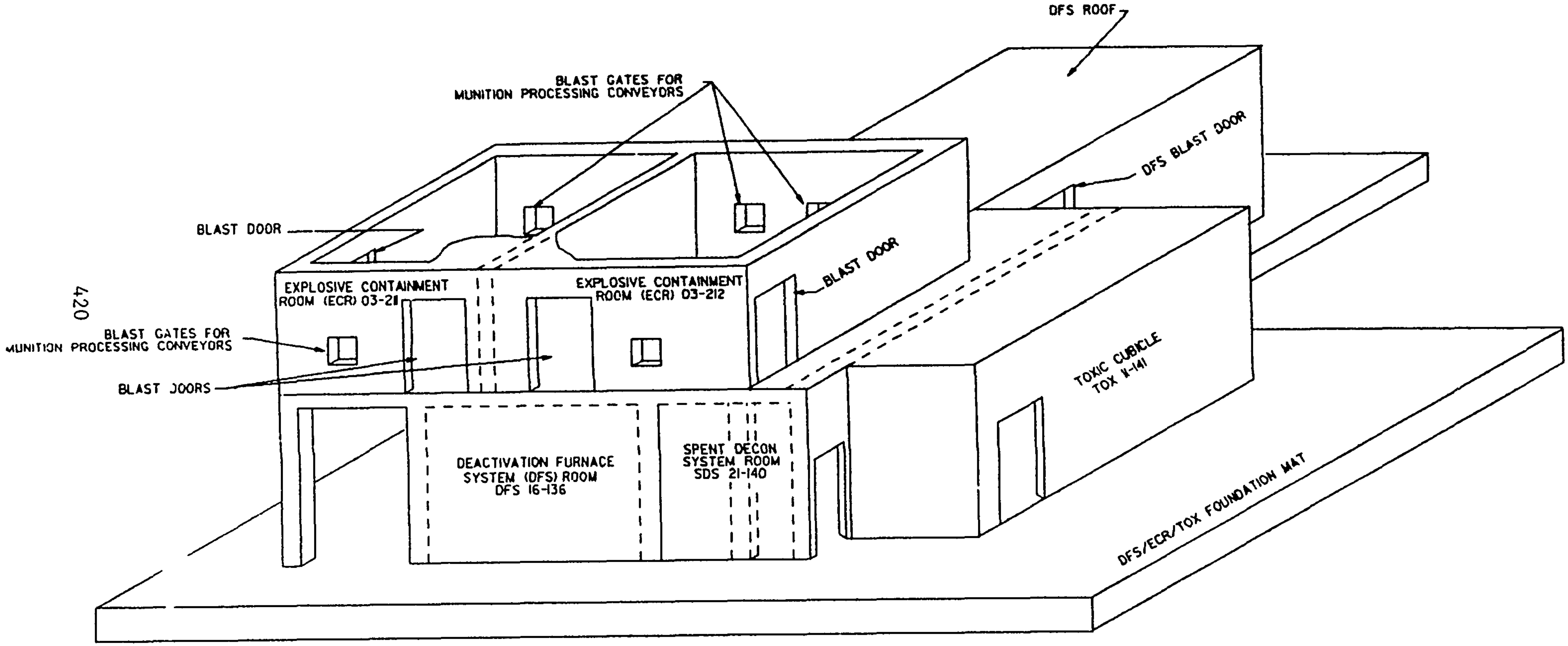


Figure 5. Isometric of blast containment structure

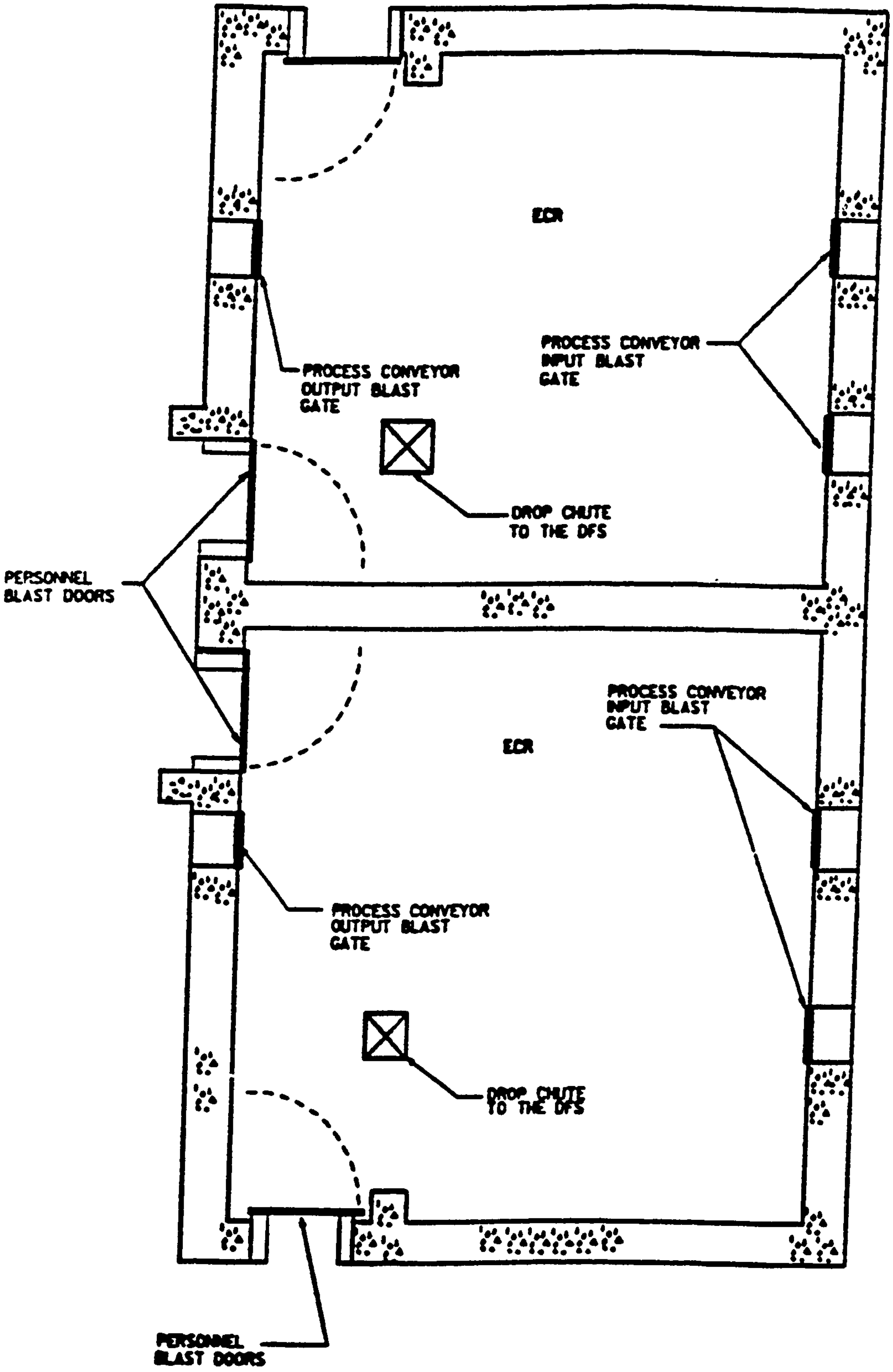


Figure 6. Containment room plan view

and the maximum amount of agent present in any one munition. It is assumed in the containment room design that all of the chemical agent present in the affected munition contributes to the blast pressure during the MCE. All explosive weights are increased by a 1.25 safety factor. The shock phase peak pressure is calculated using 15 lb. TNT as the MCE which equates to 18.75 lb. with the safety factor. In addition to the safety factor, the explosive weight for calculating shock pressures is increased by another factor of 1.25 to account for the contribution of agent combustion to this phase of the blast wave. The quasi-static blast loading results from the detonation of the munition and combustion of all of the agent in the munition. Quasi-static pressure resulting from the MCE is shown in Table 2.

Table 2. ECR quasi-static pressures for various munitions

Munition Type (Quantity)	Agent	Quasi-Static Pressure (psia)
M55 Rocket (1)	VX	42.08 (59.19)[a]
M23 Land Mine Drum)	VX	41.33
4.2-inch Mortar (1)	HT	23.81
105-mm Projectile (1)	GB	18.43
155-mm Projectile (1)	HD	31.48
M426 8-inch Projectile (1)	VX	56.35

Note: [a]Number in parentheses includes propellant burn.

Fragmentation Considerations: Chemical munitions are designed for optimum dispersion of agent rather than for fragmentation. The actual worst-case fragment mass for the containment rooms was determined from actual arena testing. All surfaces of the ECR structure are considered to be exposed to the worst-case fragment. Fragmentation shields for all penetrations are provided. All munition fragments in the DFS room originate within the furnace retort. The retort shell will confine and attenuate these fragments. In the event of a failure of the retort itself, calculations have shown that fragments are large, have low velocities, and are neither a consideration for the fragment design nor a fragment hazard to the DFS structure. The worst-case combination of blast load and fragmentation is shown in Table 3.

Table 3. Combined quasi-static and fragment penetration

Munition	Quasi-Static Pressure (psia)	Fragment Penetration (in) Concrete	Steel
M55 Rockets	42.08 (59.19)[a]	1.2	0.2
M23 Mine	41.33	18	2.4
M426 8-inch Projectile	56.35	12.2	2.3

Note: [a]Number in parentheses includes propellant burn.

Note: Minimum Wall Thickness = 25 inches (non-spall)

Deactivation Furnace System Room: After explosive components are removed from the munitions in the ECR's they are gravity fed to the rotary kiln through a blast resistant feed chute assembly. A section through the ECR and DFS rooms is shown in Figure 7. The energetic materials and related metal components in the DFS room are confined to the furnace retort. Explosives are completely incinerated and metal parts thermally decontaminated as they travel the length of the retort. Penetrations in the DFS room include one personnel door, one equipment door, two feed chutes from the ECR's above, utility penetrations, and a heated discharge conveyer. Blast hardened closures are provided for all these penetrations. In addition, an air supply and exhaust duct and a duct to the pollution abatement system (PAS) also penetrate the structure. Blast valves are provided for the ventilation intake and exhaust ducts. The duct to the PAS includes a blast attenuation duct to reduce shock pressures and act as a vent for quasi-static pressures. In the event of an explosive incident in the DFS retort, all blast and fragment effects are contained. The DFS room is also reusable with minor refurbishment after the MCE. The explosive limit of the DFS room is determined from a TNT equivalent of 28.2 lb. TNT increased by a 1.25 safety factor. This quantity is again increased by 1.25 to calculate shock pressures in order to account for enhancement of the shock pressure due to agent combustion.

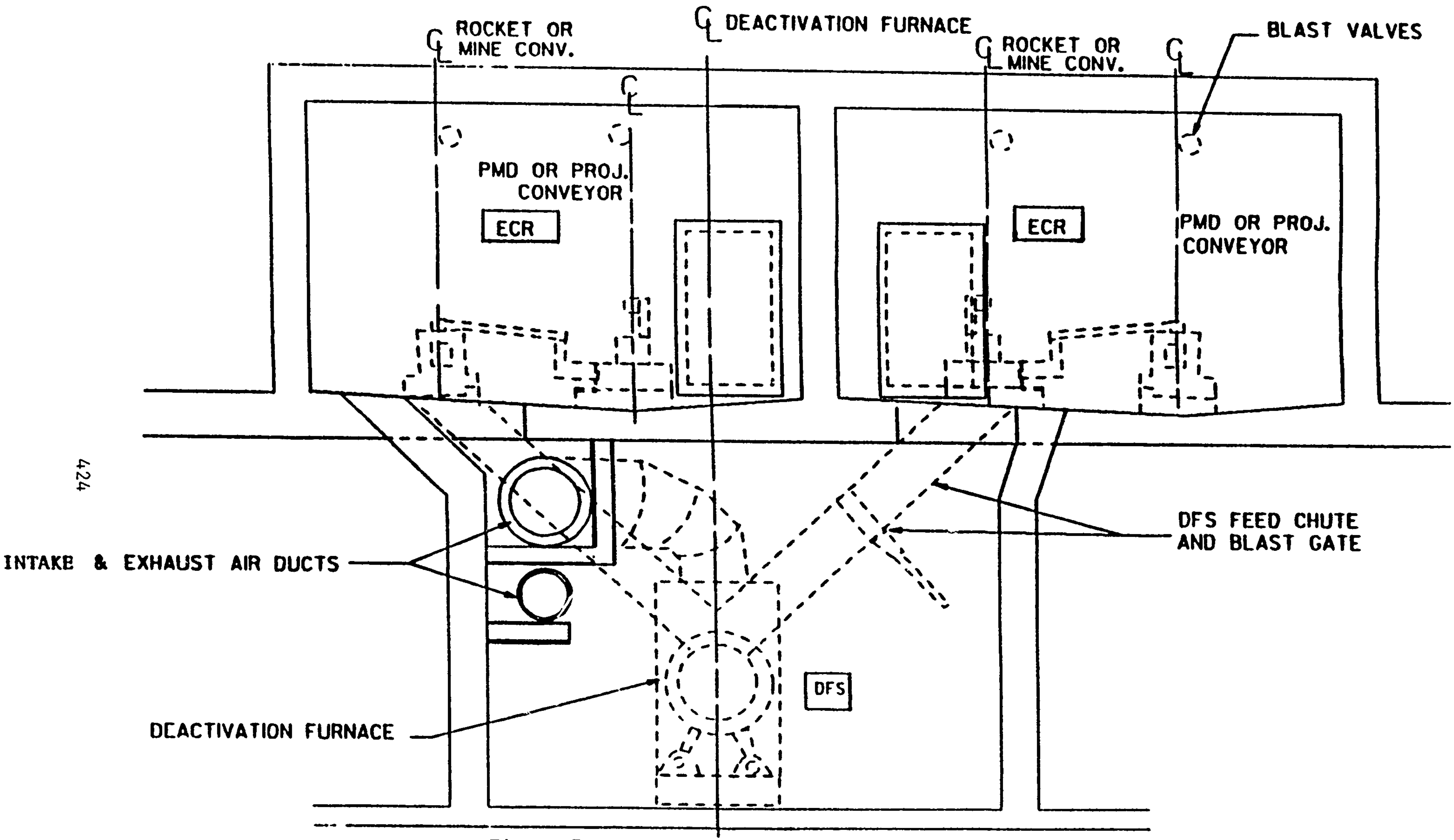


Figure 7. Section through blast containment structure

ADDITIONAL CONTAINMENT DESIGN CONSIDERATIONS

The requirement that the ECR function as a nonventing containment structure results in several additional criteria which would not normally be of significance for structure which vents rapidly. Pressure decay in a full containment structure, such as the ECR, is a function of two characteristics--structure leakage and the rate at which the confined hot gas products cool after an incident.

Ventilation System Blast Protection: Both the ECR and the DFS rooms have ventilation systems which function during normal process operations. In the event of an explosive incident, the ventilation ducts must be quickly isolated to prevent damage to them and the filter system downstream. This protection is achieved by using a fast-acting blast valve, followed by a gas-tight (isolation) valve. The maximum shock pressure rating of the blast valve is based on the maximum shock and quasi-static pressures resulting from a maximum credible event. The low pressure threshold must consider incidents such as a single projectile or mine. The gas valve provides assured closure capabilities for hazardous occurrences below the threshold of the blast valve such as a fire. Because even a "fast" blast valve has a finite closure time, some short duration shock will pass the blast valves and enter the ventilation ductwork. The ducting is designed to accommodate this transient load. Filters are located far enough away for shocks to decay, through the duct length and numerous bends, to an acceptable overpressure (less than 1 psi) at the filter.

Testing: The blast containment rooms within the MDB are reinforced concrete designed in accordance with TM 5-1300. Upon completion of construction the gas tightness of the ECR's will be quantified by performing a pneumatic leak test. This test will involve pressurization of the ECR's to 15 psig and measuring leakage to assure compliance with criteria.

CONCLUSION

Explosive containment features throughout chemical demilitarization facilities are conservatively designed to meet the most stringent conditions that could occur in the facility during processing. Containment of blast, fragment, and agent vapor resulting from an accidental detonation is assured by the conservative design approach, high quality construction to known standards, and post-construction testing. Personnel safety and agent containment are the foremost criteria utilized for demilitarization facility designs. Incineration of these munitions within the current technology environment provides the most expeditious and safest process for complete destruction of all components of the United States chemical weapon stockpile.

REFERENCES

1. "Safety Submission Mixed Munition Plant Tooele Army Depot, Utah," February 1989.

2. Chemical Stockpile Disposal Program "Facilities Project Development Brochure Tooele Army Depot Mixed Munition Plant." U.S. Army Engineer Division, Huntsville, Contract DACA78-86-C0084, May 1987.

3. "Structures to Resist the Effects of Accidental Explosions," U.S. Army Technical Manual TM5-1300, Washington, DC, June 1969.

4. "Suppressive Shields Structural Design and Analysis Handbook," U.S. Army Engineer Division, Huntsville, Manual HND-111--1-2, November 1977.

5. Whitney, M. G., Friesenhahn, G. J., Baker, W. E., and Vargas, L. M., "A Manual to Predict Blast and Fragment Loadings from Accidental Explosions of Chemical Munitions Inside an Explosive Containment Structure," U.S. Army Toxic and Hazardous Materials Agency, April 1983.

6. Powell, J. G., "Fragment Characterization Profile for Chemical-filled Munitions - M23 Land Mine, 115MM Rocket Warheads and 8-inch Projectile. Naval Surface Weapons Center, April 1983.

7. Chemical Stockpile Disposal Program, Task B-11F6: ECR Blast Analysis, Performed by the Wilfred Baker Engineering Co., Inc., through The Ralph M. Parsons Company, DACA87-86-C0084 for the U.S. Army Engineer Division, Huntsville.

8. Disposal of Chemical Weapons, Alternative Technologies, Congress of the United States Office of Technology Assessment, OTA-BP-O-95, June 1992.

INTRODUCTION

DISCOVERY OF MUSTARD GAS (LIQUID FORM)

CONGRESSIONAL LETTER

FORMATION OF USACMDA

MISSION OF USACMDA:

OVERSEE AND OPERATE CHEMICAL DEMILITARIZATION PROGRAM

TO ACCOMPLISH THE MISSION:

DEVELOP OVERALL PROGRAMMATIC PLANS

PRIORITIZE THE EFFORT FOR 200 POTENTIAL SITES

OTHER RANKING SYSTEMS

CERCLA "SUPERFUND" HAZARD RANKING SYSTEM

RCRA CORRECTIVE ACTION PRIORITIZATION

MIXED MATERIAL SITES (UXO/CSM/HTW)

(SOIL EXCAVATION ONLY)

UXO = UNEXPLODED ORDNANCE

CSM = CHEMICAL SURETY MATERIALS

HTW = HAZARDOUS & TOXIC WASTES

PRESENTATION OBJECTIVE

TO STIMULATE INTEGRATED CONCEPTUALIZATION OF POSSIBLE PRIORITIZATION AND RANKING SYSTEMS

PHILOSOPHY OF SAFETY PROFESSIONALS

VS

PHILOSOPHY OF RISK ASSESSORS

SAFETY PROFESSIONAL: PREVENT UNSAFE EVENT FROM OCCURRING

RISK ASSESSOR: EVALUATE RISKS ASSOCIATED WITH ALL POSSIBLE EVENTS

CRITICAL FACTORS TO BE CONSIDERED WHEN DEVELOPING A HAZARD RANKING SYSTEM

DETAILED SITE HISTORY

CONTAINERIZATION OF THE UXO

FUZING, ARMING AND PHYSICAL CONDITION

CHEMICAL NATURE OF MAJOR CONSTITUENTS (REACTIVITY/FLAMMABILITY)

ENVIRONMENTAL BEHAVIOR OF UXO/CSM/HTWs

CHARACTER & DISTRIBUTION OF POTENTIAL RECEPTORS

RISK ASSESSMENT CONCEPTS

RISK = EXPOSURE X HAZARD

RISK = DOSE X TOXICITY

RISK REQUIRES BOTH AN EXPOSURE (DOSE) AND A HAZARD (TOXICITY)

AN EXPOSURE (DOSE) REQUIRES A COMPLETED EXPOSURE PATHWAY

PRESENTATION FEATURES

STRUCTURED TO DETAIL UNIQUE CHARACTER OF UXO/CSM/HTW SITES

CONSIDERS COMPONENTS OF EXPOSURE PATHWAY USING RISK ASSESSMENT CONCEPTS

LISTS SUGGESTED SCORING FACTORS

DESCRIBES A "FIRST PASS" HRS

SITE CHARACTERIZATION

1. SITE RECORDS REVIEW & SURVEY TO DEVELOP SITE HISTORY/BACKGROUND.
2. PAST INVESTIGATION REPORTS/FUTURE INVESTIGATIONS
3. PHYSICAL, CLIMATOLOGICAL & HYDROGEOLOGICAL CHARACTERIZATION
4. POTENTIAL RECEPTOR ANALYSIS
5. FUTURE LAND USE STUDY
6. REGULATORY HISTORY
7. EVALUATION OF SOCIAL-POLITICAL FACTORS DEFINING SITE SENSITIVITY

EXPOSURE PATHWAY COMPONENTS

1. DETAILED RISK ASSESSMENT CONCEPTS

ELEMENTS OF THE EXPOSURE PATHWAY:

A. HAZARDOUS CONSTITUENT (UXO/CSM/HTW)

SAFETY CONTEXT: INJURY, FATALITIES, PROPERTY DESTRUCTION

CHEMICAL HAZARD: ACUTE & CHRONIC TOXICITY (TOXIC/CARCINOGEN)

B. RELEASE MECHANISM

UNCONTROLLED DETONATION; EXPLOSION, FIRE, CHEMICAL REACTION

ENVIRONMENTAL PROCESS: VOLATILIZATION; WIND MOBILIZATION; LEACHING TO GROUNDWATER

C. TRANSPORT PATH THROUGH ENVIRONMENTAL MEDIUM

AIR PATHWAY: (VAPOR/PARTICULATE) DISPERSION;

SOIL PATHWAY: PHYSICAL DISPLACEMENT; LEACHING

GROUNDWATER PATHWAY: CONVECTION; DIFFUSION

D. HUMAN OR ENVIRONMENTAL RECEPTOR

SUGGESTED HAZARD RANKING SYSTEM FACTORS

EARLY RECOGNITION OF THE OBJECTIVE OF THE HRS

TO PRIORITIZE FUNDING

RANK SITES BY LEVEL OF HAZARD

ADDRES SITES BY LEVEL OF PUBLIC SENSITIVITY

RANK BY FEASIBILITY OF RESTORATION

PATHWAY EVALUATION PARAMETERS

RELEASE POTENTIAL

TOXICITY/HAZARD CHARACTERISTICS

TARGET RECEPTORS

ELEMENTS OF THE HAZARD RANKING SYSTEM

1. LIKELIHOOD OF RELEASES (LR)

2. HAZARD (TOXICITY) CHARACTERIZATION (HTC):

   SAFETY FACTORS
   TOXICITY FACTORS

3. HUMAN AND ENVIRONMENTAL FACTORS (TR)

4. INSTITUTIONAL CONSTRAINTS (IC)

PRELIMINARY CONCLUSIONS

* IT IS ESSENTIAL TO MOUNT AN IN-DEPTH EFFORT TO DEVELOP A DETAILED SITE HISTORY TO MAXIMIZE EFFECTIVENESS OF HRS.

* CONTAINERIZATION CHARACTER IS THE MOST DOMINANT FACTOR FOR DETERMINATION OF THE HAZARDOUS CHARACTER OF THE FUDS.

* SITE CHARACTERIZATION EFFORT SHOULD BE USEFUL IN IMPLEMENTING A PRELIIMINARY PRIORITIZATION OF THE FUDS SITES.

* MINIMIZATION AND ELIMINATION OF SAFETY HAZARDS ARE THE MOST CRITICAL OBJECTIVE OF THE HRS.

* INSTITUTIONAL CONSTRAINTS MAY MAKE ANY RESTORATION EFFORT INFEASIBLE.

* PUBLIC SENSITIVITY ISSUES MAY OVERWHELM THE SCORING PROCESS, THUS CHANGING THE RANKING OF THE SITES.

* IT IS NECESSARY TO DEVELOP A DECISION-MATRIX THAT IDENTIFIES MAJOR GOALS OF THE HRS; PROVIDES SITE-SPECIFIC GUIDANCE FOR STRUCTURING THE SCORING SYSTEM; AND, ADDRESSES SOCIO-POLICICAL ISSUES.

* ANY HRS DEVELOPED FOR UXO/CSM/HTW SITES WILL BE SIGNIFICANTLY DIFFERENT THAN THE CERCLA HAZARD RANKING SCORING.

AUSTRALIAN POLICY FOR THE MANAGEMENT OF LAND AFFECTED BY UNEXPLODED ORDNANCE (UXO)

BY

LIEUTENANT COLONEL C.W. BADELOW - ROYAL AUSTRALIAN ARMY ORDNANCE CORPS
AND
MR. K. R. HUTCHISON - WESTERN AUSTRALIA POLICE DEPARTMENT - UXO BRANCH.

INTRODUCTION

1. The Australian Defence Force (ADF), like that of many other nations, has traditionally maintained a network of installations and training facilities to store, handle, maintain the ammunition and explosives necessary for the conduct of peacetime activities as well as to provide for anticipated needs in the event of defence contingencies. However, in meeting these defence needs Australia has also inherited the legacy of UXO contamination.

BACKGROUND

2. In Australia, almost all UXO contaminated sites are either current, or former military training or ammunition storage areas, used by Australia or her Allies mainly during World War II. There are some exceptions such as places bombed by the Japanese during World War II and some isolated sites where unsuccessful attempts were made to destroy unserviceable or surplus ammunition stocks. These UXO contaminated training areas were used as shore ranges for naval gunfire, bombing ranges for air forces, artillery, mortar and grenade ranges, as well as ranges for live field firing during large formation exercises and major firepower demonstrations. In many cases, the 'fall of shot' was never observed and the resultant UXO was abandoned, and, more importantly and unfortunately, left unrecorded. Such is not the case with the use of military ranges and training areas in Australia today, where strict range operating rules and UXO procedures apply.

3. During World War II, large numbers of live field firing ranges were used throughout Australia, often using land that was, at that time, considered to be both remote and isolated. But, not so today. The Australian population has grown and urban development has accelerated, while much of this land is now considered 'prime real estate', suitable for development and within easy reach of some of Australia's larger and

developing population centres.

4. On the positive side of the UXO contamination ledger, some of these firing ranges and training areas that were used were officially 'gazetted'. However, on the negative side most of these range and training areas were never declared publically for security reasons. Thus the precise location, type of ammunition fired and location of any remaining UXO is unknown. An immediate research task has been to identify from anecdotal evidence and unit histories the location of these potential UXO contaminated sites. This task has been made more difficult by virtue of the lack of any Allied unit training records or war diaries which, quite naturally, returned home with their parent units and formations at the end of World War II.

Scope

5. Australia currently holds over 1000 records of separate or individual range and training areas (and these are growing as research continues). However, a preliminary analysis of these records indicates that the majority of potential UXO contaminated sites is spread between the States of Queensland and Western Australia. This spread appears to conform to the known deployment patterns of both Australian and Allied troops who were undergoing training in Australia during the latter half of World War II. More importantly, it has been these two States which are experiencing the most pressing UXO contamination problems, due mainly to their particularly high urban growth and development rates.

6. Thus it was in this climate of accelerating urban growth complemented by a commensurate degree of land and property development that, in 1987 the Australian Commonwealth Government decided to develop a policy for 'The Management of Land Affected by UXO'. This policy was subsequently issued to all State and Territory governments in late 1990.

COMMONWEALTH POLICY

Major Policy Tenets

7. The Commonwealth's policy is based upon four major tenets. They are:

a the need to protect the public through:

(1) education programs,

(2) Public Warnings of the dangers of handling UXO,

(3) continuing to render safe all reported UXO; and

(4) restricting public access to UXO contaminated areas under Commonwealth control.

b. that the Commonwealth is generally under no legal obligation to commit resources to reduce known UXO hazards, although it may take hazard reduction action in some cases (usually where public safety is the primary issue);

c. the need to minimize UXO hazards before disposing of any Commonwealth owned land previously contaminated by UXO; and

d. to be able to influence land zoning and development proposals when appropriate.

Key Policy Elements

8. The key elements of the Commonwealth policy are:

a. **To protect the Public.** In trying to protect the public from the dangers of UXO the Defence Department has established a UXO data registration and dissemination cell which specifically:

(1) maintains a central register of all known or suspected UXO contaminated sites throughout Australia; and

(2) freely disseminates relevant extracts of this register to Local and State government land title controlling authorities to allow them to warn prospective land purchasers of the potential dangers of UXO contaminated land.

b. **To render safe discovered UXO.** The Commonwealth will continue to provide specialist ADF personnel to promptly render safe any discovered items of UXO throughout Australia.

c. **Land management considerations.** This is the most contentious policy element which focusses upon the future use of UXO contaminated land. Within this policy element there are three categories of UXO contaminated land. They are:

(1) UXO contaminated land currently owned and occupied by the Commonwealth such as Ammunition Supply Units or field firing and bombing ranges. In this category:

  (a) unauthorized trespass is minimized; and

  (b) in selecting Commonwealth land for the firing of live ammunition, preference is given to the use of land already contaminated by UXO.

(2) land which is, or has been contaminated by UXO and which the Commonwealth wishes to divest itself of legal interest. In this case, the Commonwealth will take all 'reasonable' steps to reduce the existing UXO hazard; and

(3) land which the Commonwealth has never owned, or which it has previously disposed of its legal interest. This is the most contentious category because it includes most of the World War II ranges and training areas which, were rarely on Commonwealth land and were invariably on State Government land. In this land category, the Commonwealth may in some cases reduce the level of UXO contamination provided that:

  (a) the extent of the hazard reduction program is agreed, on the basis of the proposed future use of the land in question (eg. the level of agreed hazard reduction may be greater for land proposed for urban development, than for grazing pasture); and

  (b) cost sharing arrangements and legal liabilities are clearly agreed beforehand.

Cost Sharing Arrangements

9. In assessing the Commonwealth Government's contribution toward cost sharing arrangements for proposed UXO hazard reduction programs for land in which it does not have a legal interest, the following considerations are taken into account:

a. that as a principle, the prospective land owner or developer, who should have reasonably expected to have been aware of the potential UXO hazards at the time of purchase, should bear the costs of any subsequent UXO hazard reduction program; and

b. that other factors such as any previous compensation or price discounting that may have occurred at the time of acquisition should also be taken into account.

WESTERN AUSTRALIA STATE GOVERNMENT PERSPECTIVES

Background

10. During World War II approximately 55,000 troops were stationed in Western Australia. These troops while occupying defensive positions immediately North and South of the state capital Perth, were also training extensively using 'undeclared' range and training facilities.

11. In 1940 the population of Perth was 255,000. The population in 1992 is 1.4 million which exemplifies the city's rapid growth rate.

12. In 1988 the State government started to become aware of the extent of UXO contamination within the Perth environs. As a result a Western Australia UXO Working Party was formed with the specific task of investigating and reporting on areas previously used for military ranges and training areas. Subsequently this Working Party decided that a dedicated State register of known or suspected UXO contaminated sites should be compiled. Currently, 214 UXO contaminated or suspected sites have been identified.

Warnbro Range

13. An example of UXO pollution in Western Australia is a former artillery and bombing range 55 kms (34 miles) South of Perth. This area is now known as Warnbro and is approximately 4000 hectares (9880 acres) in size.

14. In the late 1970's the Northern portion of this former range was developed as a housing estate resulting in the discovery of a number of items of UXO. At this time, the Commonwealth government did not have a UXO land management policy, and ensuing negotiations between the State and Commonwealth Governments resulted in the latter agreeing to fund a UXO search of the area. This search was conducted by the Western Australia State Government and completed in early 1988 resulting in the discovery of over 2500 shells and bombs. Subsequently, and based upon the search equipment employed, the area was assessed as suitable for 'occasional recreation'.

15. Late in 1988 a number of Warnbro landowners applied for approval to further subdivide their land for residential development. However, despite the initial Commonwealth Government funded search, it was considered that a further and more detailed search should be conducted in view of the proposed future use of this land with its inherent risks to public safety. Accordingly the State Government Department of Planning and Urban Development (DPUD) approved these subdivisions subject to:

a. arrangements being made to ensure the land has been searched for UXO to the satisfaction of the State Government Police Department (UXO Branch); and

b. the subdivider making arrangements to the satisfaction of DPUD to ensure that the purchasers of the proposed subdivisions were informed concerning the existence of UXO.

16. The method and degree/level of searching varied but usually involved a search prior to, and at the conclusion of any earthworks. All search costs were borne by the subdivider.

17. The Warnbro UXO site was a major range with clearly defined natural and artificial boundaries. Thus, there was never any question that it had to be thoroughly searched for UXO. However, later experience has shown that it is not always possible to be as definitive toward all UXO contaminated or potentially contaminated sites.

Range North of Perth

18. A further example of UXO contamination is an area North of Perth comprising 350 hectares (865 acres). Previous anecdotal evidence suggested that part of this area had been used as a mortar range.

19. The costs of a 100% search of this area was considered prohibitive. Thus a two percent pattern search was initially conducted which successfully located this range, estimating its' area at approximately 36 hectares (89 acres). The remaining area was immediately cleared for development without the need for further searching.

Commonwealth Government Policy Considerations

20. Payment of the considerable costs associated with searching for UXO is a contentious issue. The Commonwealth Government "Policy For The Management Of Land Affected By UXO" allows for each case to be considered on its merits. However, the Western Australia Government does not accept the contention of the Policy that "The Commonwealth (Government) is generally under no legal obligation to commit resources to reduce known hazards associated with UXO contamination". In addition, the Western Australia Government disputes that the Commonwealth Government should be able to influence the planning and the future use of UXO polluted areas. These aspects have been raised with the Commonwealth Government and it is hoped that the policy will be modified to accord with the views of the Western Australia Government.

Conclusion

21. Australia is not the only nation to inherit a legacy of UXO pollution. The primacy of public safety and environmental pollution issues in combination, will ensure that UXO hazard reduction needs and programs have to be met. This challenge requires a co-ordinated and co-operative approach by all Governments and Local authorities to resolve those contentious issues which are outstanding.

22. The Commonwealth Government considers that it has produced a sound and viable policy document which permits specific UXO contamination issues to be addressed on their merits. Not withstanding individual State concerns, these issues must be met in a spirit of mutual trust, understanding, and in the best interests of the public.

RANKING COMBINED UXO/CSM/HTW SITES REQUIRING RESTORATION: AN INITIAL PROTOCOL

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ABSTRACT

The need to develop a Hazard Ranking Scoring (HRS) methodology was created the discovery of buried mustard gas at the Raritan Arsenal, a Formerly Used Defense Site (FUDS) in New Jersey. The U.S. Army Chemical Materiel Destruction Agency (USACMDA) was formed to address the problem. One of its major objectives is to prioritize 200 potential sites that are possibly contaminated by Chemical Surety Materials (CSMs).

An in-depth site characterization is required to provide high quality input data for the ranking process. A detailed site history is of utmost importance to initially achieve the system's objective. This is particularly necessary for these sites because of the wide spectrum of hazards associated with CSMs.

A HRS protocol is presented in the context of investigation and restoration activities, that utilizes health risk concepts as the overall unifying mechanism. It is limited to one major activity, i.e., restoration of the soil medium at potential CSM sites. A distinction is made between safety hazards and health risks based on the basic philosophies of safety professionals and risk assessors. Included in the presentation is a customized and detailed analysis of the components of the major exposure pathway, a decision matrix to assist in classifying these sites, and a generalized and all-encompassing scoring procedure for prioritization. Conclusions are derived from this initial effort to provide some guidance for future endeavors in this field.

INTRODUCTION

The need to develop a ranking system was created by the discovery of mustard gas, a chemical surety material (CSM), during the restoration of the deactivated Raritan Arsenal in New Jersey. To further complicate matters the CSM was also found in adjacent areas, which had already reverted to public use. This event triggered a congressman's letter to the President (1). A program by the Department of Defense (DoD) to address the situation is rapidly developing in the newly formed U.S. Army Chemical Materiel Destruction Agency (USACMDA). It's mission is to oversee and operate the chemical demilitarization program. To accomplish that mission, USACMDA will develop overall programmatic plans and prioritize the effort to clean the estimated 200 formerly used defense sites (FUDS) that are suspected of chemical weapons (CW) material contamination (2). In addition to CSMs, the sites may also contain unexploded ordnance (UXO), and hazardous and toxic wastes (HTW) (2).

Prioritization needs are similar to those experienced by the U.S. Environmental Protection Agency (U.S. EPA) in startup of their regulatory programs authorized by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) also known as "Superfund," and the Resource, Conservation and Recovery Act (RCRA). CERCLA had already developed a second generation Hazard Ranking System (HRS) for uncontrolled hazardous substances release as Appendix A of the statute's regulations entitled the National Oil and Hazardous Substances Contingency Plan (NCP) (3). For the RCRA program, internal guidelines are used to systematically implement enforcement of this statute. This presentation uses the CERCLA HRS as a guide to a "first pass" effort at developing a ranking system for the Defense Environmental Restoration Program (DERP).

This paper considers a mixed materials site with CSMs, UXO, and HTW. A HRS protocol to address the ranking requirement is described in the following presentation, in the context of investigation and restoration activities. It utilizes health risk concepts as an overall unifying mechanism. It is not the objective of this presentation to provide a fully developed procedure for ranking the 200 sites, but to raise issues that must be addressed by any ranking

effort, and to present some possible development approaches. It is limited to one major activity, i.e., restoration of the soil medium at possible UXO/CSM/HTW sites.

An important distinction based on philosophies practiced by safety professionals and risk assessors is made between safety hazards and health risks. A risk assessor will presume that an unlikely events, e.g., detonation or violent chemical reaction with a subsequent fire will occur with some probability. The safety professional's goal is to reduce that probability to zero by implementing protective measures. Emphasis of this of this presentation is generally placed on health risk issues. However, it is recognized that the most critical elements of a hazard ranking system must address safety concerns. Therefore, it is presumed that safety hazards can be eliminated or controlled by the use of remote operating procedures, and specially constructed enclosures designed to contain releases of CSM in the event of a UXO detonation.

A detailed site history is of utmost importance for initially achieving the objective of any ranking system. The results of the ranking can be no better than the availability and accuracy of needed data that are qualitatively or quantitatively used as input to the system.

Behavior of the different classes of hazardous materials; i.e., UXO, CSM, and HTW, are very dependent on whether a detonation and/or violent reaction with subsequent fires occurs. The potential for a catastrophic event is totally dependent on: (a) containerization of the CSMs; (b) fuzing, arming and physical condition of UXO, and; (c) chemical nature of the major constituents related to violent chemical reactions and fires.

Barring detonations, violent chemical reactions and fires; environmental fate and transport of the toxic chemicals (all three categories are chemicals) may be the most significant aspect of the site. Migration potential is dependent on their chemical, biological and physical nature . Future use of the site will have a bearing on the level of effort needed to restore the site.

Potential receptors are defined as both onsite and offsite persons that could be exposed to hazards posed by the site. Their location as a potential exposure location, numbers, demographics and distribution will have decisive effect on public sensitivity and political viability.

The presentation is structured to detail the unique characteristics of a UXO/CSM/HTW site; comprehensively consider the components of an exposure pathway using risk assessment concepts; lists suggested scoring factors; and describes a "first-pass" hazard ranking system.

SITE CHARACTERIZATION

A listing of the elements of a site characterization in the context of a restoration activity, namely excavation and removal of soil contaminated with UXO, CSMs and HTWs is illustrated in Figure 1. There may be other aspects of the site that are specific to any one case. Consequently, it is not all inclusive. It is essentially equal to the level of effort used to characterize a CERCLA site, and is required in the RCRA permitting and corrective action programs.

Data generated by the site characterization effort are the basic input of the HRS. For the purposes of this presentation, the site characterization includes: (1) a site records review and survey by interviewing knowledgeable people to generate a history of the facility's activities from its inception to closure; (2) past investigation reports and future investigations containing information regarding the possible presence of CSMs, UXO, and HTWs that include waste characterization and chemical constituent identification; (3) physical, climatological and geological characterization of the site; (4) a potential receptor analysis; (5) future land use; and (6) regulatory history and an evaluation of the social-political factors defining public sensitivity to the site.

All of these components are presented in the context of potential exposure to hazardous and toxic materials from possible dispersion of CSMs from accidental detonation of UXO, violent chemical reactions and fires, and environmental transport of toxic constituents offsite.

The most important element of the site characterization is the site records review and survey since the possible entities may range from discarded CSM kits (most likely-with the CW agent dispersed to the environment 40 to 50 years ago) to buried containers (containing acutely toxic material) that are still intact.

The receptor analysis will provide insight into the public sensitivity of the location, and future land use will allow estimation of restoration costs and public pressures. The site setting, i.e., material attributes and extent of contamination are factors that assist in developing a restoration plan. Quality of the information generated from the site characterization will significantly affect the quality of the scoring of that particular site.

EXPOSURE PATHWAY COMPONENTS

Understanding of two simple risk assessment concepts are needed to follow the reasoning embedded in the procedure described in this paper: (a) there is no risk if either of two elements are missing, i.e., exposure and hazard; (b) a complete pathway is required for an exposure to occur. Figure 2 illustrates these concept in graphical form.

Elements included in an exposure pathway (in risk assessment terms) include: (1) a toxic agent (UXO, CSM or HTW); (2) a mechanism that releases the toxic constituent, i.e., detonation, violent chemical reaction, soil disturbance with release of particulates, mists or vapors, natural evaporation of a volatile constituent; (3) transport path through an environmental medium; and (4) a human and/or environmental receptor. Figure 3 shows the components of the exposure pathway and some aspects of each in specific aspects of a UXO/CSM/HTW situation.

Generally, the safety professional will try to reduce the risk to zero by making certain that a complete pathway is not present. Safety clothing, protective equipment, adherence to proven standard operating procedures, and performance of hazardous operations using remote methods are the tools of his trade. The risk assessor will postulate a complete pathway and attempt to quantitate a probability or qualitatively determine the potential for each of the exposure pathway components to exist at that particular site.

A combination of all three hazardous material classes present an extremely complex situation. This is due to: (1) the wide range of possible injuries and the toxicological extremes exhibited by the different material classes; (2) radically different levels of exposure contingent upon uncontrolled detonation, violent chemical reactions and/or fires; and (3) because most CSMs are not persistent in the environment, a dependency on extent and nature of the containerization.

Consequently, the release mechanism is a more critical factor in scoring a UXO/CSM/HTW site, and contrary to a Superfund site HRS evaluation where health risks associated with long-term exposure are the main concern. The potential for accidental release with rapid and extensive dispersion of the toxic constituents is the overwhelming concern for a combined UXO/CSM/HTW site.

The major transport pathway in this context is particulate dispersion to ambient air during soil excavation. Releases can be radically altered by a detonation or violent reaction from mixing of incompatible chemical constituents. The nature of the CSM may be such that concern for potable water sources may be a factor. Table 1 adapted from the United Nations report on the efficacy of chemical warfare (4) provides water solubility, volatility and hazard duration for various CSMs. It provides some comparative data that is useful for the evaluation of the migration-potential of these materials.

Proximity of human receptors is an important factor in characterizing the potential impacts of releases of hazardous constituents. The major exposure mode is inhalation of the dispersed air particulates, as dermal absorption may not be significant depending on the time frame (sufficient time for the UXO/CSM/HTW to break down to non-toxic constituents).

An understanding of the exposure pathway components and the critical factors that affect exposure is used to develop the decision matrix described in the next section.

SUGGESTED HAZARD RANKING SYSTEM FACTORS

As a first try at developing a HRS for UXO/CSM/HTW sites, it was immediately apparent that some sort of decision matrix would be required. This was necessitated by the complexity of the toxicity and exposure scenarios. Figure 4 shows an embryonic decision flow diagram with the various paths taken depending on many decisions reached during execution of the HRS.

An early recognition of the objective of the HRS is needed to perform a cost-effective evaluation. Main objectives of any HRS are to prioritize funding, rank sites by the level of hazard, address the sites by the level of public sensitivity, and finally by feasibility of restoration. The most likely basis for ranking will be the potential hazards and risks posed by the site.

However, if there is no distinct delineation between sites on this basis, funding may be a factor. An overriding factor may be institutional constraints. If restoration is totally constrained by socio-political concerns making it unfeasible, then a review of options may be required.

The initial scoring procedure entails selecting viable exposure pathways and evaluating those pathways using three parameters: (a) release potential; (b) toxicity/hazard characteristics; and (c) target receptors. These are the same aspects used to rank Superfund sites for the National Priority List (NPL). Various numerical scores are developed for each of the three aspects similar to the procedure described in the NCP (3). Relative weighting factors are applied to the numerical scores.

In addition, a fourth scoring parameter, labeled "institutional constraints" is applied. Its numerical value ranges from zero for a restoration that is totally constrained (the site cannot be restored due to regulatory or public concerns) to 100 if there are no constraints. All four scoring parameters (three weighted using CERCLA methods, and one with a weighting factor of 1) are multiplied. This product is then divided by a scaling factor to normalize to a top score of 100.

In this manner, sites can be ranked in accordance with the need for addressing the presence of the hazardous and toxic material. Figure 3 presents possible aspects that qualitatively characterize release potential, numerical hazard/toxicity parameters, and target receptor qualities that allow evaluation. The list is not all-inclusive.

ELEMENTS OF THE HAZARD RANKING SYSTEM

The proposed HRS is divided into the four major components: (1) likelihood of releases; (2) hazard characterization, which is further subdivided into safety and toxicity factors because they are radically different; (3) human and environmental receptors; and (4) institutional constraints. See Figures 4A to 4C for a graphical representation of these elements.

LIKELIHOOD OF RELEASE (LR)

There is some potential for release of air particulates, and/or vapors and mists during the excavation and removal of contaminated soil containing UXO/CSMs/HTWs. Important factors

affecting the nature and release of air particulates during excavation and removal (restoration) are:

- Containerization status of the various classes of materials:

  UXO: CSM contained in UXO, or another container in close proximity to UXO, UXO condition (fuzed, unfuzed/unarmed; fuzed/armed) and state of deterioration of container. other toxic materials.

  CSMs: In buried drums.

  HTWs: buried drums or other containers.

- Soil disturbance with wind mobilization, wind erosion
- Transport in ambient air dependent on wind and atmospheric stability.
- Particulate settling dependent on aerosol characteristics of the particles, wind, and atmospheric stability.
- Intensity of physical displacement during excavation.
- Chemical and physical properties affecting soil adsorption, biodegradation, leaching.
- Ability of any specially constructed containment design to contain an accidental release.

Release of vapors and mists during excavation and removal of affected soil and its contents are affected by:

- Containerization of volatile constituents in shells, drums.
- Enhanced emission due to soil disturbance, opening of soil pore vapors to ambient air.
- Diffusion and dispersion rate are dependent on wind and atmospheric stability.
- Environmental degradation processes in ambient air, e.g., photolysis.

- Chemical and physical properties of the hazardous/toxic constituents that affect: soil absorption, leaching.

From the above listing it is evident that migration-potential play an important role in the likelihood and criticality of the release. Volatility, particle size, persistence in soil, photolysis, ambient air mixing based on meteorology are some of the characteristics that determine the nature and extent of the release. As previously stated, the most dominant factor is the type and completeness of the containerization.

HAZARD (TOXICITY) CHARACTERIZATION (HTC)

As conceptualized in this "first-effort" HRS, hazards and toxicity are considered separately. Hazards are considered in the greater context and considered to be safety oriented. Toxicity is characterized in terms of acute and sub-chronic toxicity for the onsite restoration personnel and workers at a partially active installation.

Safety Hazards

With regard to safety issues, the type of release mechanism is the most critical item. Initiation of the UXO fuze on the UXO with subsequent detonation causing fires and possible violent chemical reactions, is the most dominant scoring factor for a UXO/CSM/HTW site. This aspect may overwhelm the scoring, just as large potentially exposed population located near a Superfund site dominate the NPL rankings. It may be more practical to include sites associated with containerized CSMs and suspect FUDS with UXO containing CSMs into a separate category. It is also possible that there are no sites of this type in the 200 FUDS being considered by USACMDA. Actual existence of the "worst case" postulation must be established.

Chief safety concerns include: injuries/fatalities due to fire and/or violent chemical reaction due to accidental detonation of a CSM-containing shell with rapid dispersion before warnings and/or evacuations can be effective. This is the worst-case situation. Products of combustion may be more or less toxic with the remote possibility that "imminently dangerous to life and health" (IDLH) conditions may arise. Fuze type and the specific characteristics of the

UXO is a consideration regarding hazards faced by restoration personnel. General safety hazards that are enhanced by site characteristics would also be considered in arriving at a HTC score.

Toxicity Considerations

Toxicity of the chemical constituents in all of the hazardous materials categories are considered in relation to onsite workers and the general public. For the onsite workers; acute and subchronic toxicity, and the pattern of contamination are a concern. Limited exposure is expected in the short-term time frame. Chronic toxicity and carcinogenicity are pertinent for the general public. Lifetime exposure at an offsite location where the toxic constituents may migrate is the major issue. Presence of sensitive populations has some influence on the scoring in this classification. There may be other aspects of the health hazards to consider. A intensive effort to develop a more detailed HRS after the sites have been characterized is needed to pinpoint other factors requiring consideration.

HUMAN AND ENVIRONMENTAL TARGET RECEPTORS

Target receptors are divided into the risk assessment categories of onsite and offsite groups. The onsite group includes restoration personnel, onsite workers, visitors and trespassers. Terrestrial and aquatic flora and fauna are also considered in the onsite context. This was the case for the restoration of the Weldon Spring Ordinance Site in Missouri because it had become a wildlife refuge after deactivation. Offsite receptors encompass the general population and offsite flora and fauna.

Aspects to consider within this context include spatial distribution of the offsite population into upwind and downwind categories to determine the most exposed individual (MEI); and to also characterize the population, i.e., the most sensitive segment (aged and children).

Terrestrial fauna and flora and the general ecology are considered in the development of TR scores.

INSTITUTIONAL CONSTRAINTS

Institutional constraints may preclude the restoration of a FUDS if public sensitivity is intense, regulatory compliance cannot be met, and socio-political issues make it totally unfeasible to proceed. However, this may be an extreme scenario. There are regulatory and political constraints on some restoration technologies. The furor regarding the siting of a CSM-incinerator near Louisville is an example of this situation. National security issues may override all constraints. However, this is also an extreme situation at the opposite end of the spectrum of restoration choices. Future use of the site may place a limit on the restoration choices available. All of these items will have a significant effect on the restoration costs.

PRELIMINARY CONCLUSIONS

Some preliminary conclusions can be drawn from initial development of a HRS for UXO/CSM/HTW sites. These are:

- It is essential to mount an in-depth effort to develop a site history that will maximize the goal of cost-effective allocation of restoration funds.
- Containerization character is the most dominant factor for determination of the hazardous (safety-related) character of the FUDS.
- The site characterization effort should be useful in implementing a preliminary prioritization of the FUDS sites.
- Minimization and elimination of safety hazards are the most critical objective of the HRS. Main attention should be on sites expected to present potential for catastrophic releases. Health protection, both short- and long-term are of secondary importance in the HRS scoring procedure.
- Institutional constraints may render any restoration effort as being unfeasible.
- Public sensitivity may overwhelm the scoring process, thus changing the ranking of some sites. These sites may require prompt restoration activities, regardless of their technical and scientific aspects.

- It is necessary to develop a decision-matrix that identifies major goals of the HRS, provides site-specific guidance for the structure of the scoring system, and addresses socio-political issues.

- Any HRS developed for UXO/CSM/HTW sites will be significantly different than the CERCLA Hazard Ranking Scoring.

The ideas and guidance generated by development of this initial HRS should be beneficial in starting an in-depth study that will result in a cost-effective, health-protective, and safe program that addresses the problem of UXO/CSM/HTW FUDS in the United States.

REFERENCES

1. Public letter from the Honorable Bernard J. Dwyer, Member of Congress to President George Bush dated January 29, 1992.

2. Personal communications of James P. Pastorick with personnel of the U.S. Army Chemical Material Destruction Agency, June-August, 1992.

3. Federal Register dated December 23, 1988. Hazard Ranking System (HRS) For Uncontrolled Releases; Appendix A of the National Oil and Hazardous Substances Contingency Plan; Proposed Rule. Volume 53, page 51962.

4. Report of the Secretary-General of the United Nation titled "Chemical and Bacteriological (Biological) Weapons and the Effects of Their Possible Use." Department of Political and Security Council Affairs. New York: 1969.

TABLE 1. SOME PROPERTIES OF SELECTED CHEMICAL WARFARE AGENTS

1	Sarin	VX	Hydrogen cyanide	Cyanogen chloride	Phosgene	Mustard gas	Botulinal toxin A	BZ	CN	CS	DM
2	Lethal agent (nerve gas)	Lethal agent (nerve gas)	Lethal agent (blood gas)	Lethal agent (blood gas)	Lethal agent (lung irritant)	Lethal and incapacitating agent (vesicant)	Lethal agent	Incapacitating agent (psycho-chemical)	Harassing agent	Harassing agent	Harassing agent
3	Vapour, aerosol or spray	Aerosol or spray	Vapour	Vapour	Vapour	Spray	Aerosol or dust	Aerosol or dust	Aerosol or dust	Aerosol or dust	Aerosol or dust
4	All types of chemical weapon		Large bombs	Large bombs	Mortars, large bombs	All types of chemical weapon	Bomblets, spray-tank	Bomblets, spray-tank	All types of chemical weapon		
5	1 000 kg	1 000 kg	1 000 kg	1 000 kg	1 500 kg	1 500 kg	400 kg	500 kg	750 kg	750 kg	750 kg
6	100%	1-5%	100%	6-7%	Hydrolysed	0.05%	Soluble	?	Slightly soluble	Insoluble	Insoluble
7	12 100 mg/m³	3-18 mg/m³	873 000 mg/m³	3 300 000 mg/m³	6 370 000 mg/m³	630 mg/m³	Negligible	Negligible	105 mg/m³	Negligible	0.02 mg/m³
8 (a)	Liquid	Liquid	Liquid	Solid	Liquid	Solid	Solid	Solid	Solid	Solid	Solid
(b)	Liquid	Liquid	Liquid	Vapour	Vapour	Liquid	Solid	Solid	Solid	Solid	Solid
(a)	¼-1 h	1-12 h	Few minutes	Few minutes	Few minutes	12-48 h				—	
9 (b)	¼-4 h	3-21 days	Few minutes	Few minutes	Few minutes	2-7 days	—	—	—	2 weeks for CS1; longer for CS2	—
(c)	1-2 days	1-16 weeks	1-4 h	¼-4 h	¼-1 h	2-8 weeks				—	
10	> 5 mg-min/m³	> 0.5 mg-min/m³	> 2 000 mg-min/m³	> 7 000 mg-min/m³	> 1 600 mg-min/m³	> 100 mg-min/m³	0.001 mg (oral)	100 mg-min/m³	5-15 mg/m³ concentration	1-5 mg/m³ concentration	2-5 mg/m³ concentration
11	100 mg-min/m³	10 mg-min/m³	5 000 mg-min/m³	11 000 mg-min/m³	3 200 mg-min/m³	1 500 mg-min/m³	0.02 mg-min/m³	?	10 000 mg-min/m³	25 000-150 000 mg-min/m³	15 000 mg-min/m³
12	1 500 mg/man	6 mg/man	—	—	—	4 500 mg/man	—	—	—	—	—

KEY:
1. Common name
2. Military classification
3. Form in which the agent is most likely to be disseminated
4. Types of weapon suitable for disseminating the agent
5. Approximate maximum weight of agent that can be delivered effectively by a single light bomber (4-ton bomb load)
6. Approximate solubility in water at 20°C
7. Volatility at 20°C
8. Physical state (a) at −10°C
   (b) at 20°C
9. Approximate duration of hazard (contact, or airborne following evaporation) to be expected from ground contamination:
   (a) 10°C, rainy, moderate wind
   (b) 15°C, sunny, light breeze
   (c) −10°C, sunny, no wind, settled snow
10. Casualty-producing dosages (for militarily significant injuries or incapacitation)
11. Estimated human respiratory LC_{50} (for mild activity: breathing rate approx. 15 litres/min)
12. Estimated human lethal percutaneous dosages

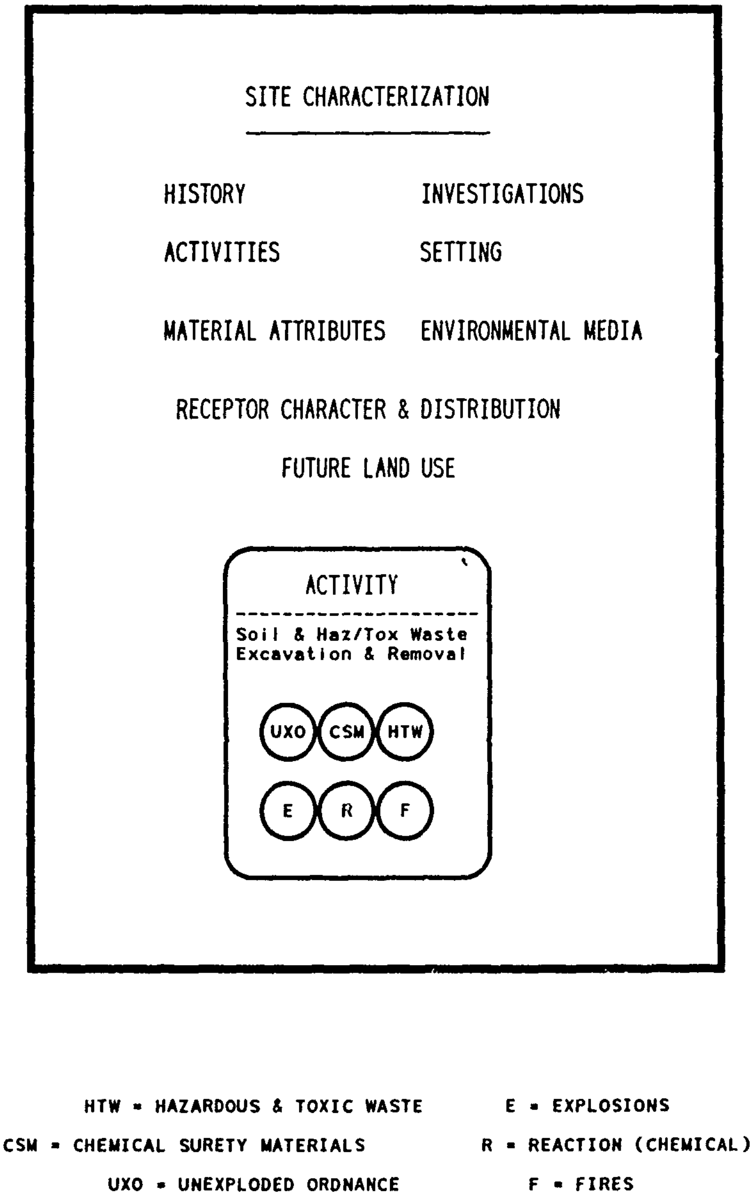


FIGURE 1. ELEMENTS OF THE SITE CHARACTERIZATION

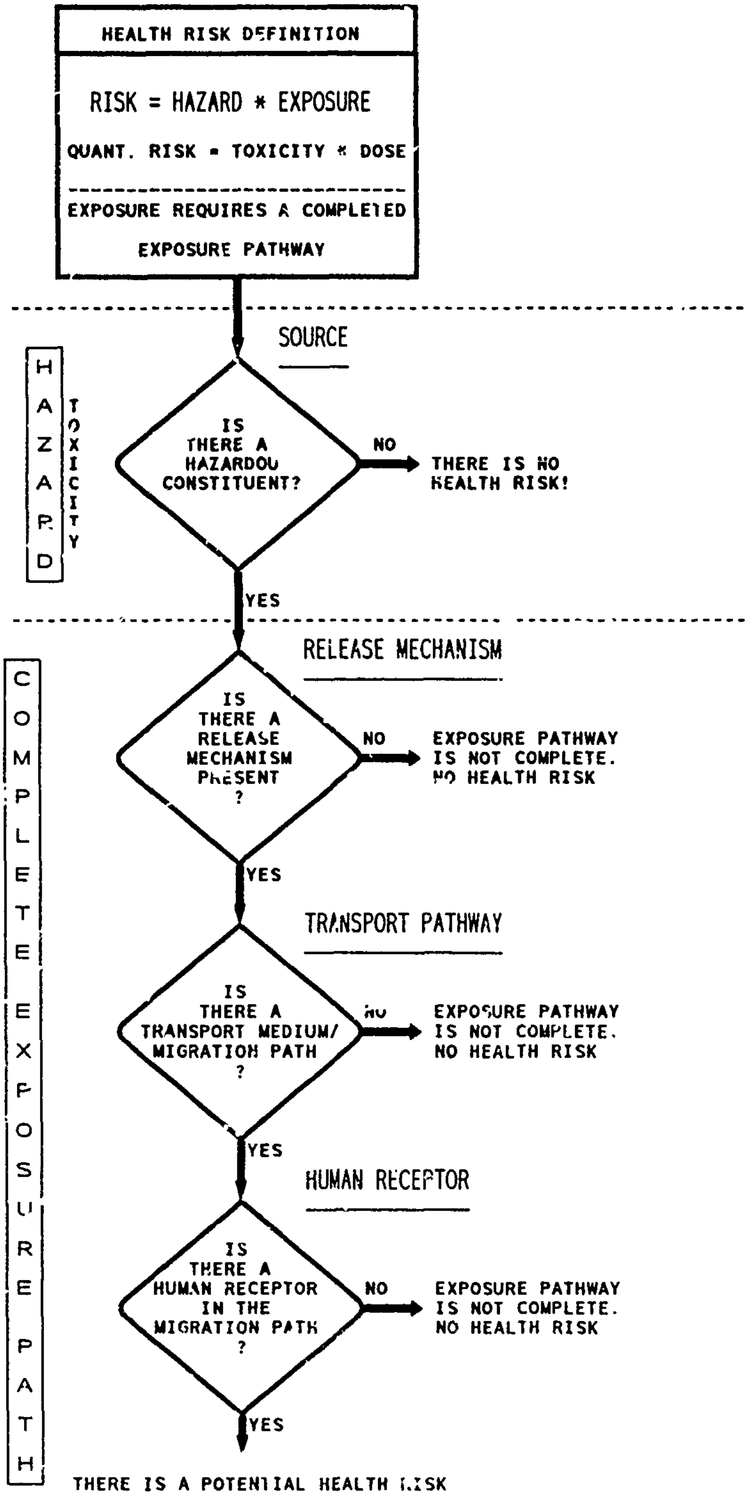


FIGURE 2. HEALTH RISK CONCEPTS ASSOCIATED WITH RISK ASSESSMENT

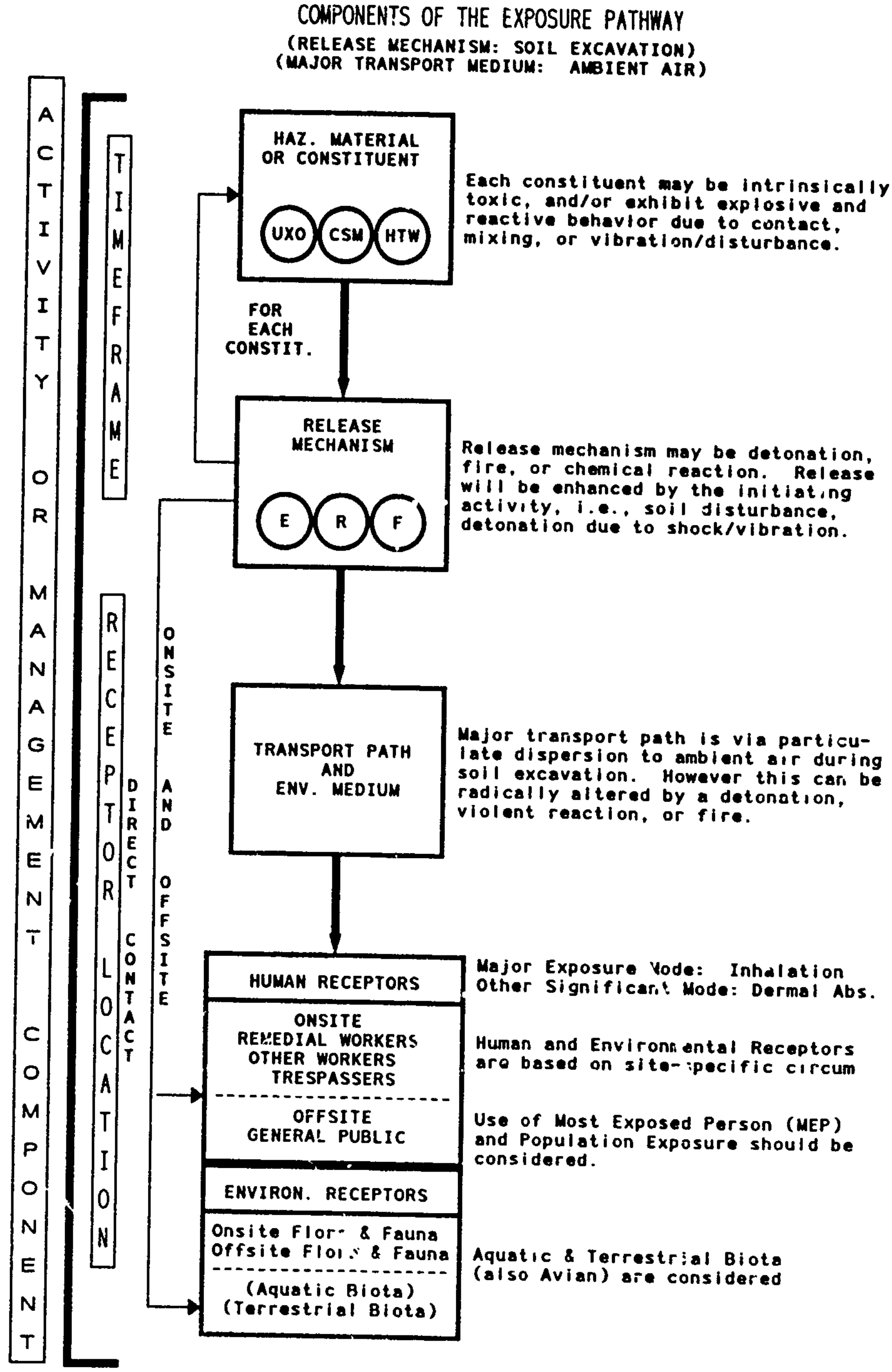
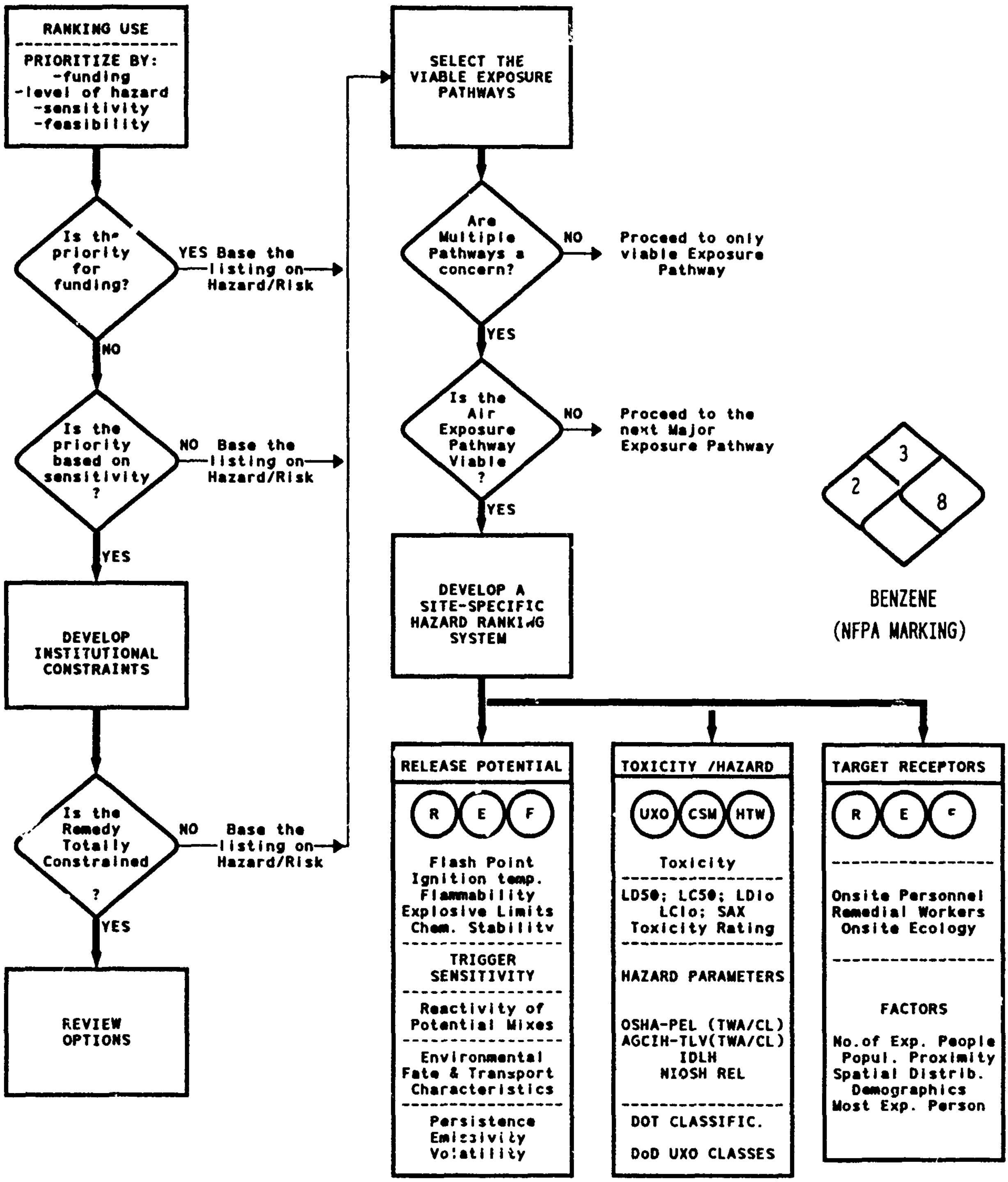


FIGURE 3. EXPOSURE PATHWAY COMPONENT FACTORS

SUGGESTED HAZARD RANKING SYSTEM FACTORS



SF = Scaling Factor (Normalize to 100)
IC = Institutional Constraint = 0 or 1

$$HRS = \left[\frac{[(W_1 * LR) * (W_2 * HTC) * (W_3 * TR)] * IC}{SF} \right]$$

FIGURE 4. HRS DECISION MATRIX FOR PROCEDURE DEVELOPMENT

HAZARD RANKING SYSTEM ELEMENTS

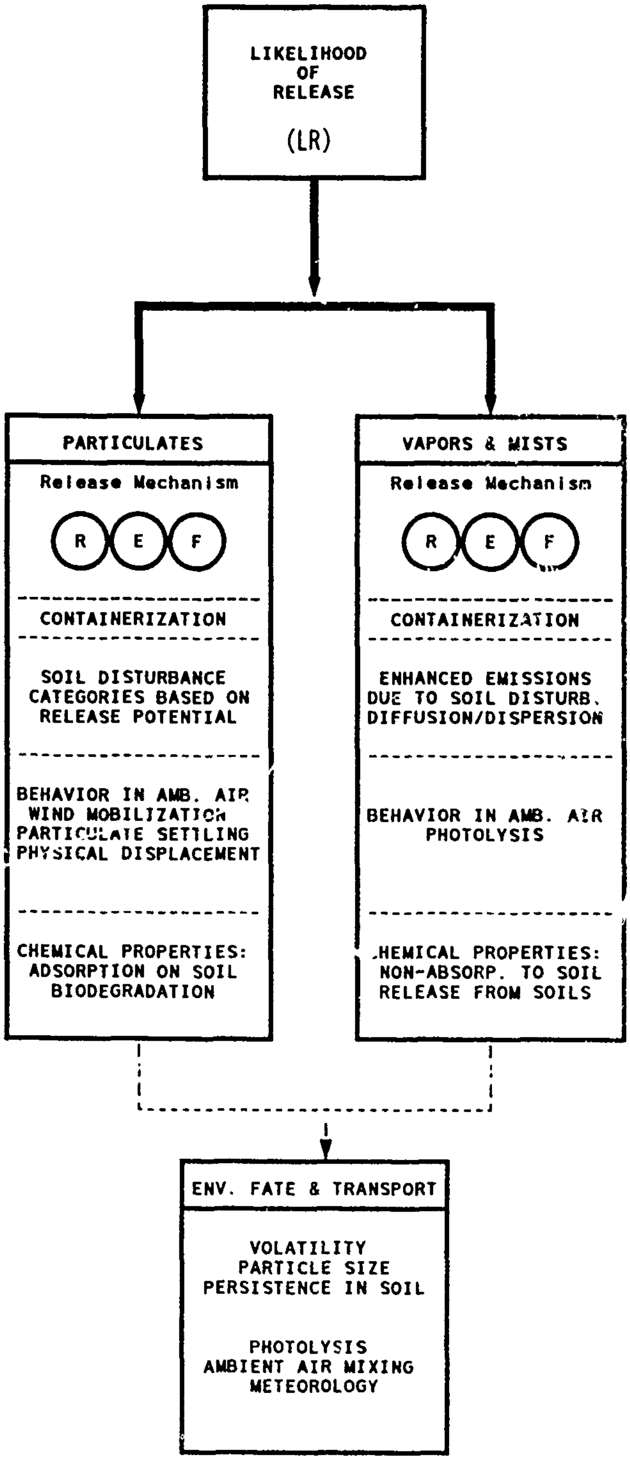


FIGURE 5A. HAZARD RANKING SYSTEM ELEMENTS

HAZARD RANKING SYSTEM ELEMENTS

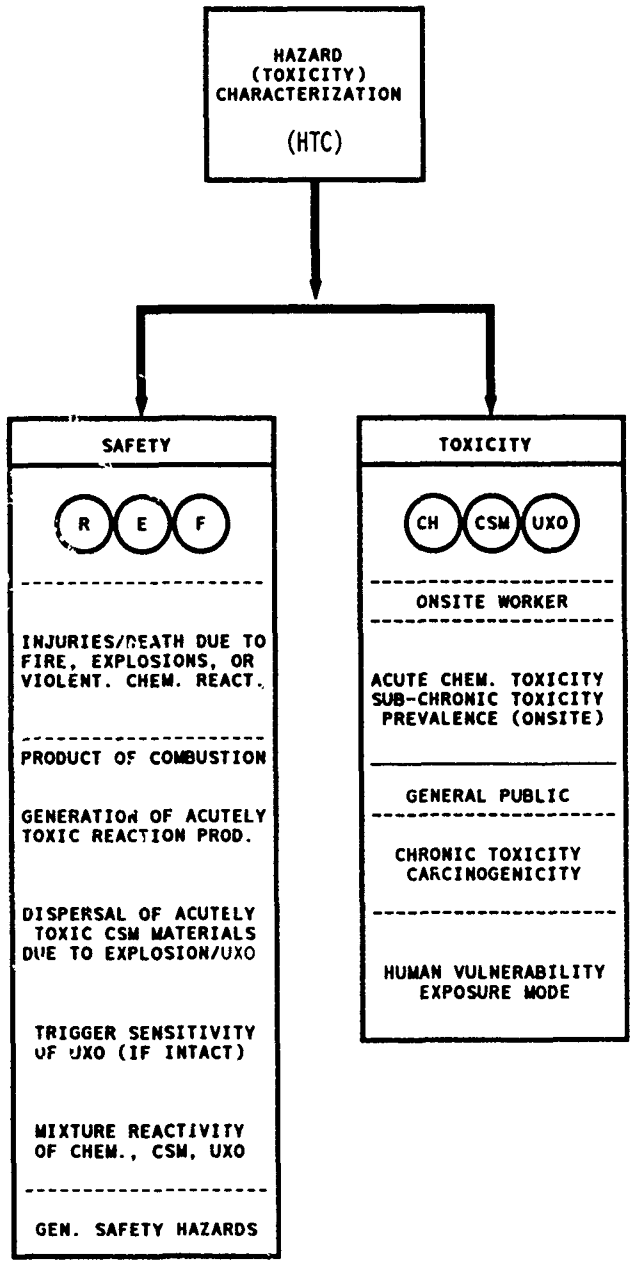
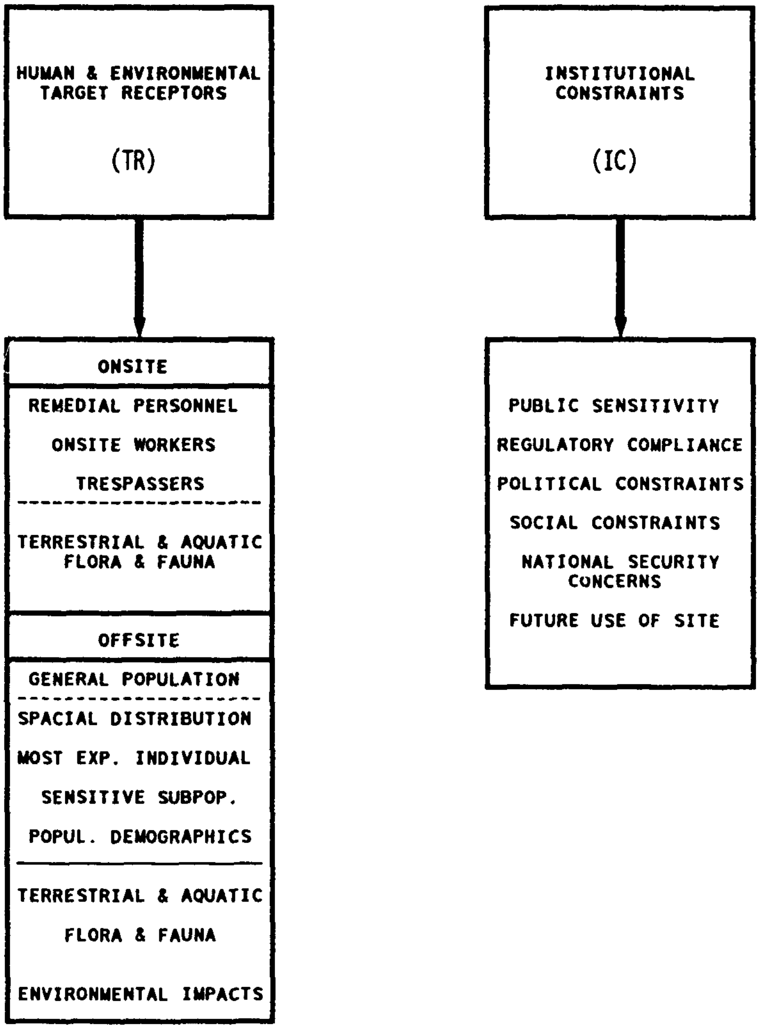


FIGURE 5B. HAZARD RANKING SYSTEM ELEMENTS

HAZARD RANKING SYSTEM ELEMENTS



$$HRS = \left[\frac{(W * LR) * (W * HTC) * (W * TR) * (IC)}{(SF)} \right] IC$$

SF = SCALING FACTOR (To normalize to 100)
IC = INSTITUTIONAL CONSTRAINT = 0 OR 1

FIGURF 5C. HAZARD RANKING SYSTEM ELEMENTS

Structural Response and Resulting Quantity-Distance Debris Collection Techniques and Results

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Introduction

One of the important factors in citing protective aircraft shelters (PAS) is the quantity of explosives that can safely be stored inside a PAS. The maximum amount of explosives depends upon the distance to other inhabited facilities and the distribution of peak overpressures and debris which might result from an accidental detonation of the stored explosives. Experimental data provides the basis for calculation of minimum separation distance between explosive stored and other types of base facilities. These separation distance are referred to as explosives quantity-distance (Q-D) criteria and are normally specified as scaled ranges form the source of the explosion.

A new aircraft shelter designed by the Norwegians is under construction in Norway and will be used by NATO forces. The front door and other structural details of this shelter differ significantly from the US Third Generation design. These differences have raised questions regarding the applicability of the Q-D criteria derived from previous test programs. The Norwegian and US government entered a Memorandum of Understanding to address these concerns. The test program included the construction of four 1/3 scale structural models of the PAS. These models were subjected to internal detonations of various weights of high explosives. This paper will discuss response of the shelter and associated debris.

Test Structure and Model

The test structure was a 1/3rd scale model of the Norwegian/US PAS design. The structure is illustrated in figure 1. The Norwegian/US design is similar to the US Third Generation PAS design, but differs significantly in the door and structural details. The door is one piece made to two steel plates with a stiffeners between the two plates. The arch and rear wall have the same type of shape but there is about three times the steel in the Norwegian/US design.

The reinforced concrete shelter was analyzed using the finite element code DYNA3D run on a SUN workstation. An elastic-plastic material model was used. The assumed material properties are given in table 1. The yield strength was determined by assuming a steel ratio of .027, and assuming a

TABLE 1. ASSUMED MATERIAL PROPERTIES	
Parameter	Reinforced Concrete
Young's Modulus (gPa)	30.0
Poisson's Ratio	0.2
Density (kg/cu.m.)	2403
Yield Strength (mPa)	3.7
Hardening Modulus	0.0
Hardening Parameter	0.5

yield strength of the reinforcing bars and steel line of 60000 psi. Figure 1 shows a schematic of the assumed cross section of the shell. The pressure time history used were generated by GUSH3D and actual data. The pressures used for the three tests are shown in figure 2 for the various areas.

Quantity-Distance Program Plan

In an attempt to fully document and characterize the Q-D response of the 1/3rd scale US/Norwegian aircraft shelter, an extensive debris collection program and free-field overpressure measurement plan was generated. Four methods were used to collect debris data: Four, 5 degree collection sectors were defined, which emanated from GZ. All fragments remaining within these sectors post test were collected and thoroughly documented. A 360 degree survey of large debris was made, which was used to determine symmetry of the structure breakup. Fragment collection packs were used to collect debris, and help determine areal densities in the vertical plane. High speed photography was used to record initial velocities of large discernable fragments, or to track photo poles attached to them. Free field gages, both passive and active were located throughout the test bed, which were used to determine the 1.0 psi (6.89 kpa) contour.

The following is a list of debris collection requirements for the 1/3rd scale US/Norwegian aircraft shelter tests. Parameters are based on TO-11A-1-47[1], study of the Distant Runner[3] (DR) full scale, and 1/10th scale test programs. Collections zones, methods, dimensions, and the like, meet or exceed TO requirements and parallel DR research so that comparisons, if possible, can be made between the two shelter types. It is believed that enough similarities exist between the arch's of these two shelters that useful data or generalized information can be gained from this comparison

Fragment Parameters

Minimum collectable fragment dimensions are based on results from DR. From DR, it was determined that a minimum fragment mass of 0.3 lbs (136 gm)[3] would bound the lower limit of the 58ft-lb kinetic energy criteria (hazardous fragment for personnel). At 1/3rd scale, the minimum fragment mass is .011 lbs (5.04 gm). These minimum requirements are pertinent only to the 5 degree sectors where all fragments are being collected. Applying this and a reinforced concrete density of 150 lbs/ft^3, yields the following 1/3rd scale minimum criteria:

- Minimum acceptable dimension for collection purposes: That which can be captured by a sieve with a square mesh of 0.50 inch (12.80 mm) separation. Fragments which pass through such a mesh will be ignored.
- Mass: > 0.01 lbs (5.04 grams), which is the mass of a 0.5 inch cube of reinforced concrete.

Table 2 shows sieve sizes used for collecting fragments. Sizes were chosen, based on the TO and 1/10th scale tests, with additional sizes being used to reduce labor requirements for data collection. All sieve sizes are rounded to the nearest industry standard. Relative mass for a cube is also shown in table 2. For the 360 degree survey, initial plans were to limit fragment collection to Those fragments ≥ 5.00 inch (127 mm), which shall be surveyed and labeled in place.

TABLE 2. Sieve Sizes

Mass	Sieve Size (inch:mm)	Scaled Mass (lbs:gm)	Full Scale (lbs:gm)
1	0.500: 12.80	0.011: 4.82	.29: 132.89
2	0.625: 15.87	0.021: 9.61	0.57: 259.55
3	0.750: 19.05	0.036: 16.11	0.99: 448.50
4	0.875: 22.22	0.058: 26.38	1.57: 712.19
5	1.000: 25.40	0.087: 39.37	2.34: 1.63k
6	1.250: 31.75	0.170: 76.90	4.58: 2.08k
7	1.500: 38.10	0.293: 132.89	7.91: 3.59k
8	2.000: 50.80	0.694: 314.99	18.75: 8.50k
9	2.500: 63.50	1.356: 615.22	36.62: 16.61k
10	3.000: 76.20	2.343: 1.06k	63.28: 28.70k
11	4.000: 101.6	5.550: 2.52k	150.00: 68.04k

Areal Distributions: 5° Collection Sectors

Primary fragment collection sectors consist of 5° arcs of length R (figure 3), where R is a function of Net Explosive Weight (NEW), and is then subdivided into segments of length r_0 (16.40 ft (5 m): 49.22 ft at full scale). Sectors emanated from GZ, except sector 4, which is shifted reward so that its center line passes through a rear corner of the arch. Sector 4 does emanate from the longitudinal line parallel to the arch walls, which passes through GZ. The four collection sectors are defined as follows:

- Sector 1: Perpendicular to door.
- Sector 2: Perpendicular to left side arch (as viewed when facing the front of the shelter).
- Sector 3: Perpendicular to rear wall.
- Sector 4: 135° from the longitudinal axis passing through the left rear corner of the shelter (as viewed when facing the front of the shelter)

For the first three NEW's scheduled, R was defined by the relationship $75W^{1/3}$ for the first two tests (W is NEW in lbs ($29.75Q^{1/3}$: Q-kg)). For test 3 the sponsor felt that this relationship may not provide sufficient collection area, therefore R was increased to match the DR events 4 and 5's maximum collection ranges. US/Norwegian shelter test 3 represents 90% of the NEW used

in DR event 4, and 20% of DR event 5. R was rounded up to the nearest 10 m increment and was defined, by test, as follows:

test 1: R1 = 164.04 ft (50 m).
test 2: R2 = 229.65 ft (70 m).
test 3: R3 = 656.20 ft (200 m).

For test 3, R3 would have been 328.08 ft (100m), had the original relationship been used. The first sub-sector (r_0) starts at 32.81 ft (10 m) from GZ, which is near the berm's edge, perpendicular to the shelter. Subsequent sectors are spaced at intervals of r_1.

Rectangular Collection Areas For PAS-1 & 2; Zero Q-D Evaluation

In addition to the 5° sectors, the sponsor requested two rectangular regions, providing a collectior area for all manner of fragments within the "zero" Q-D region (that region which is between GZ and r_0). The first region runs the length of the shelter arch and extends from GZ to r_0. The second region runs the width of the arch/front face of the shelter, and extends from the arch/front face to r_0. It is hoped that the collection debris in these regions will help quantify future computer codes/calculations, and better establish methods used to determine debris throw within the "zero" Q-D region.

360° Ground Survey; 180° Collection Sectors

For the 360° survey, fragment recovery was originally limited to a minimum size of 5.00 inch (127 mm). Such fragments were to be surveyed, labeled and recorded individually. But, as will be shown later, this was unrealistic because of the limited number of large fragments.

The 360° survey area was divided into two 180° collection sectors. Sectors were divided into primary and secondary, based on the level of debris recovery effort. Sectors emanated from GZ and extend to R. Minimum collectable fragment size for the primary sector was originally set at 5 inches (127 mm). Minimum fragment size for the secondary sector was originally set to 10 inches (254 mm). All such fragments which fall within these criterion were surveyed in place with respect to range and angle from GZ. The zero degree radial emanated from GZ and extended perpendicularly through the shelter door. Angles are measured positive in the clock-wise direction. A debris map was generated from these surveys.

Fragment Recovery Packs

Fragment Recovery Packs (FRP's) were used to determine areal densities in the vertical plane, without concern for penetration depth or angle. Previous fiberboard recovery packs have proven to be too dense or resilient to allow fragment penetration, preventing effective data collection. Therefore, a new method was used for this series of test. For PAS-1 this consisted of a 55 gallon drum, cut in half, and lined with foam. For the remaining tests, the FRP's were constructed from 4'x8' sheets of plywood, shaped to create traps similar to the drums (figure 4), and were also foamed lined. The intent of these traps was to allow the fragments to impact the foam, limiting secondary breakup, and rebound to the floor of the trap, thereby increasing the number of recovered fragments.

For PAS-1, a single drum has a frontal area of 5.04 ft^2 ((0.47 m^2) 1.83 ft w x 2.75 ft h), while the plywood traps, used for the remaining tests, had a frontal area of 21.33 ft^2 ((1.98 m^2) 8 ft w x 2.67 ft h (2.44m h x 0.81m w)). FRP's were placed at r_1 and incrementally spaced by r_0, just out-side of the 5° sectors, alternating left and right sides. For PAS-1, FRP's were placed along side the arch, rear wall, and the 135° collection zones. For the remaining tests FRP's were limited to the arch collection radial, due to the number of plywood traps available. Traps were placed at the anticipated 1 psi range and farther. Recovery packs were aligned side-by-side with their front faces perpendicular to GZ. Placed in this manner, recovery packs subtend a solid angle not less than 0.013 steradians[1].

As a special note, the following documents recovery pack placement and numbers, which follows procedures outlined in TO-11A-1-47. The minimum frontal area for traditional full-scale FRP's is 32 ft^2, and 3.55 ft^2 at 1/3rd

scale. The drums used scale up to 5.5 ft w x 8.25 ft h (1.68 m w x 2.51 m h), yielding a full-scale frontal area of 45.4 ft^2 (4.22 m^2). The plywood traps yielded a frontal area of 192 ft^2 (17.83 m^2) at full scale. The minimum number of packs used is the "subtend (of) a solid angle not less than about 0.013 steradian."[1] A steradian is defined as "the total face area of the recovery packs (A) divided by the square of the distance (R) between the test stack and the recovery packs (A/R steradians)." The results of these requirements are in table 3.

Table 3. Number of Required Recovery Packs
Basic Equation: A/R=s

Description	r_0	$r_0 + r_1$	$r_0 + 2 * r_1$
s	0.013	0.013	0.013
A_{fp}	5.04	5.04	5.05
D_{1st}	32.81	49.22	65.62
R	1,076.0	2,422.0	4,306.0
A	13.99	31.49	55.98
A/A_{fp}	2.78	6.25	11.11
# Bins	3	7	12

Initial Velocities

Initial velocity was to be established through three methods, based on high speed photography and digital analyses of the film; digitizing large discernable fragments, photo poles, and metal/sifcon cubes of known size and mass (sifcon is a concrete & metal fiber mix, developed by NMERI). Large discernable fragments are those fragments which can be positively identified from a frame to frame analyses of high speed film images. In some cases fragments on film can be identified with recovered fragments. For the photo poles, twelve were place along the arch, and three on the front door (figures 5 and 6). Twenty five sifcon cubes (17.88 lbs (8.11 kg) and 0.49 ft^3 (150 mm)) were placed on the arch (for PAS-1, aluminum cubes, 2 inches cubed were used: placement is shown in figures 7 and 8, while the remaining tests used sifcon cubes for their traceability on film: placement is shown in figures 9 through 11). All cubes were numbered so that their impact point could be compared with their starting point. The use of sifcon was preferred since it better simulated the density of the arch.

COLOR CODES

The arch was divided into sixteen distinct segments (figure 12), using a combination of dye and colored beads mixed in with the aggregate. Dye colors

change in discrete elements from foundation to arch peak, in horizontal lifts. The beads change colors from front to rear of the shelter in lateral segments. Volume of beads used in the aggregate/reinforced concrete mix did not exceed 1% of the volume of concrete. Exhaust port, backwall, front wingwall, door segments and right half of the arch were left uncolored (natural grey) concrete. The arch color coding is shown in table 4.

Table 4: Arch Color Coding				
Concrete Dye				
Test	Red	Black	Yellow	Green
PAS-1	0° - 35°	35° -45°	45° - 60°	60° - 90°
PAS-2,3,4	10.6°-33.2°	33.2° - 60°	60° - 90°	0° - 10.6°
Pellet Color				
Test	Red	Black	Yellow	Green
PAS-ALL	1st qrt	2nd qrt	3rd qrt	4th qrt

Free Field Pressures

Static overpressure gage placement for PAS-1 through 4 are shown in figure 13, and coordinates are recorded in table 5.

PAS-1 Structural Damage and Response

This test detonated 3.7kg of C4 explosives in the center of the 1/3rd scale structure. The analysis indicated that the peak acceleration would be 1100G's, while the recorded was 1700g's, figure 14 shows a comparison of predicted vs recorded acceleration. The maximum principal stress was found to be 2.8 mpa. Somewhat lower than the yield strength of the material as shown in figure 15. It was anticipated from the analysis that the structure would respond in the elastic regime for the first test and did. The test structure suffered only minor damage in the first test. No cracks were observed in the visible portions of the arch foundation, and there did not appear to be any separation between the top of the arch foundation and the line base channel. In addition, no separation between the concrete of the arch and top of foundation could be detected on the exterior of the structure. There was no discernable outward movement of the arch foundation. The pattern of hairline cracks was observed in the floor slab around the surface GZ. Within these cracks, and construction joints, the floor slab dished downward to 18 mm at GZ.

Table 5. Free Field Gage Coordinates								
	PAS-1		PAS-2		PAS-3		PAS-4	
GAGE	X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)
701	-3.0	0.0	-5.0	0.0	-9.0	0.0	-9.0	0.0
702	-5.0	0.0	-9.0	0.0	-24.0	0.0	-24.0	0.0
703	-7.0	0.0	-14.0	0.0	-34.0	0.0	-44.0	0.0
704	-9.0	0.0	-24.0	0.0	-44.0	0.0	-74.0	0.0
705	-3.4	8.0	-3.4	8.0	-54.0	0.0	-84.0	0.0
706	-6.2	10.8	-6.2	10.0	-6.2	10.8	-6.2	10.8
707	6.8	8.0	-16.4	21.0	-16.4	21.0	-16.4	21.0
708	6.8	12.0	6.8	8.0	-23.4	28.0	-30.4	35.0
709	17.0	8.0	6.8	12.0	-30.4	35.0	-37.4	42.0
710	19.8	10.8	6.8	16.0	6.8	12.0	6.8	12.0
711	19.0	0.0	6.8	24.0	6.8	40.0	6.8	40.0
712	21.0	0.0	17.0	8.0	6.8	50.0	6.8	50.0
713	23.0	0.0	19.8	0.0	17.0	8.0	19.8	10.8
714	6.8	-8.0	30.0	21.0	19.8	10.8	30.0	21.0
715	6.8	-12.0	18.0	0.0	30.0	21.0	44.0	35.0
716			21.0	0.0	23.0	0.0	23.0	0.0
717			23.0	0.0	37.0	0.0	37.0	0.0
718			37.0	0.0	47.0	0.0	57.0	0.0
719			6.8	-8.0	57.0	0.0	77.0	0.0
720					6.8	-12.0	6.8	-12.0
721					6.8	-50.0	6.8	-40.0
722							6.8	-50.0

I the heavily reinforced portion of the floor slab between the door pit and the rest of floor slab, several hairline cracks were observed running parallel to the axis of the structure. A gap was noted between the floor slab and the back wall. The most dramatic cracking in the structure was found at

the intersection of the parapet and the top of the front walls on both sides of the structure. Although the crack pattern in the parapet seemed quite symmetrical about the centerline, it was judged that there was slightly more cracking and damage at the right side (side without personnel entrance). Figure 16 illustrates the arch hairline cracks that were observed. The structure was determine as structurally sound and reused for PAS-3.

PAS-1 Preliminary Debris Collection Results

Collection zones, radials, FRP locations, ect, are shown in figure 17, for PAS-1. For PAS-1, no fragments were found, either in the 5° sectors, rectangular collection areas, or in the FRPs. In the 360°region two fragments were located, which came from the front door-jam area. Free field data was collected and is summarized in table 6 and figure 18 shows the 1 psi contour.

Table 6. PAS-1 Static Overpressure

Gage	PSI	Gage	PSI	Gage	PSI
701	1.125	706	0.22	711	0.19
702	0.9	707	0.072	712	0.27
703	0.6	708	0.064	713	0.66
704	0.49	709	0.084	714	0.055
705	0.3	710	0.055	715	0.038

PAS-2 Structural Damage and Test Results

This test detonated 11.11 Kg of C4 explosives in the center of 1/3 scale structure. The analysis predicted that the accelerations would be on the order of 2500g's a while the recorded was 4200g's, figure 19 shows a comparison of predicted vs recorded acceleration. The maximum principle stress for the structure was on the order 3.8 MPa, which is at the yield level as shown in figure 20. It was believed the structure was on the verge of failure for this loading condition.

The structure did indeed fail; it split in two pieces. The front two-thirds of the structure was lifted off the foundation and thrust froward 1 m. The door was blown out 30 m in front of the structure. The structure split apart at a splice location. There was severe cracking on the exterior of the shelter as well as the floor slab. The arch-foundation connection failed in tension as the front two thirds of the shelter was lifted off the foundation and moved forward. The arch section remain intact except for the section that landed on the wingwalls as the structure moved forward. Figure 21 illustrates the failure of the structure as well as the splice locations.

PAS-2 Preliminary Debris Collection Results

For PAS-2, which was the third test in this series, was performed on a second, virgin shelter (figure 22 shows the test bed layout and parameters). Very few fragments were collected in this test as in PAS-1. No fragments were found in the TRPs. In this test, structure break-up was very favorable to Q-D issues. It is believed that it can be safely said that the low end NEW for zero Q-D is established with this test. This statement is based on the lack of debris outside the plan view of the arch. The 1 psi contour is shown in figure 23. Table 7 shows static overpressure results (question marks by values indicate unresolved questions about the data point).

Table 7: PAS-2 Static Overpressures

Gage	PSI	Gage	PSI	Gage	PSI
701	1.7	708	0.04	715	0.8
702	0.95	709	0.02?	716	0.51
703	0.55	710	0.02?	717	—
704	—	711	—	718	0.04
705	0.15?	712	0.1?	719	
706	1.15?	713	0.1?		
707		714			

PAS-3 Structural Damage and Test Results

This test detonated 33.33 kg of C4 explosives inside the center of the 1/3rd scale shelter. The analysis predicted maximum accelerations on the order of 4000g's while recorded was 5200g's, as shown in figure 24 a comparison of predicted vs recorded acceleration. The structure was expected to break up with pieces of the structure moving at 40 m/s. The finite element analysis used was successful at predicting the initial acceleration and velocity of the structure. The maximum principal stress was greater than the yield stress. This indicated that the structure would come part during the test. Stress concentration occurred at the bottom of the arch were the finite element model was pinned and at the top of the structure as shown in figure 25. This indicated that the structure would lift off the arch footing foundation since this was considered the weak link in the structure. This was evident post-test, as the rebar in the arch-footing connection showed classic tension failure in the rebar.

The structure had severe damage post test. It broke into seven major sections as shown in figure 26. An inspection of high speed photography

showed that the structure lifted off the foundation before the breakup occurred. It was evident that the arch-footing connection failed in tension. The door was blown out of the structure and had significant yielding.

PAS-3 Preliminary Debris Collection Results

PAS-3 was tested on the first shelter, the same shelter used in PAS-1 (test bed layout is shown in figure 27). The only issues of concern for the use of this structure would be fragment size (smaller), which could also increase the number of fragments, and allow an early release of the door from the arch, thereby relieving the arch of some impulse. But, considering the size of the charge, it was believed that these effects would be small.

Again, the shelter's response is favorable to Q-D issues. Because the arch moved vertically, with very little horizontal motion, debris containment was assured. Rock rubble scatter was due to the vectored velocity component placed on it due to the arch wall slope and vertical motion. Fragments went as far as 98 m, yet tended to be relatively small in size. A rock rubble distribution map is shown in figure 28. The 1 psi contour is shown in figure 29, and overpressures are shown in table 8.

Table 8: PAS-3 Static Overpressures					
Gage	PSI	Gage	PSI	Gage	PSI
701	6.93	708	1.32	715	—
702	2.63	709	0.85	716	1.92
703	1.77	710	1.49	717	0.93
704	1.3	711	0.85	718	0.59
705	0.85	712	0.6	719	0.37
706	2.89	713	5.1	720	1.47
707	—	714	1.05	721	0.56

PAS-4 Preliminary Debris Collection Results

PAS-4 was a 100kg charge. Test bed preparation paralleled PAS-3. Again, as in PAS-3, arch break-up moved vertically, limiting debris throw. Results of debris collection is not available at this time, but pressure data is. Table 9 shows overpressures. Figure 29 illustrates the 1 psi contour, while figures 30 and 31 show pressure level comparisons for the four tests performed to date.

Conclusion

Overall, the effects of the added steel in the arch design for this shelter can be seen. The arch has a tendency to remain together longer and in larger pieces, thereby forcing a majority of the hazardous materials and debris to move vertically, and not in the horizontal plane. But, it can not be determined at this time, if any benefits, or additional hazards are created by the use of rock rubble. At this point in time, it is felt that it does not pose any additional threat.

The use of passive foil pressure gages, for each of these tests, has proven to be of little or no benefit. This has been due to the effects of debris. In a majority of the cases, some quantity of small, dust like debris was found trapped behind the foil of the gage. The presence of debris of any kind leaves the foil data suspect, and therefore was not recorded herein. It has become apparent, that in this test environment, where debris is expected, the foil gages perform poorly.

Table 9: PAS-4 Static Overpressures

Gage	PSI	Gage	PSI	Gage	PSI
701	13.34	709	1.088	716	4.279
702	3.916	710	6.092	717	2.103
703	1.668	711	2.139	718	1.233
704	0.870	712	1.595	719	0.711
705	0.725	713	3.597	720	6.817
706	5.656	714	1.233	721	1.886
707	2.103	715	0.761	722	1.523
708	1.197				

References

1. *Department of Defense Explosives Hazard Classification Procedures*, TO 11A-1-47, Dec 1989.

2. Ward, J.M., *DISTANT RUNNER - Debris Recovery and Analysis Program for Events 4 and 5, Minutes of the 20th Explosives Safety Seminar*, DOD Explosives Safety Board, Volume II, ADA 124401, pp. 1837-1881, Washington DC, Aug 1982.

3. Bryant, M.S., Dr. E.H. Bultmann, J.E. Marsh, L.A. Walker, R. Jarrett, H.T. Webster, *DISTANT RUNNER Test Program*, AD-B075361, DNA-5964F, Defense Nuclear Agency, Washington, DC 20305, Apr 1982.

4. Ward, J.M., M.M. Swisdak, Jr., P.J. Peckham, W.G. Soper, R.A. Lorenz, *Modeling of Debris and Airblast Effects From Explosions Inside Scaled Hardened Aircraft Shelters*, AD-B105-064, NSWC TR 85-470, Naval Surface Weapons Center, Dahlgren, VA 22448-5000, May 1985.

5. Bultmann, E.H., Schneider, B.A., *Combined Norwegian/US Aircraft Shelter Quantity-Distance Program - PAS-1 Test Event*, Letter Report, NMERI, University of New Mexico, Albuquerque 87131-1376, July 1992

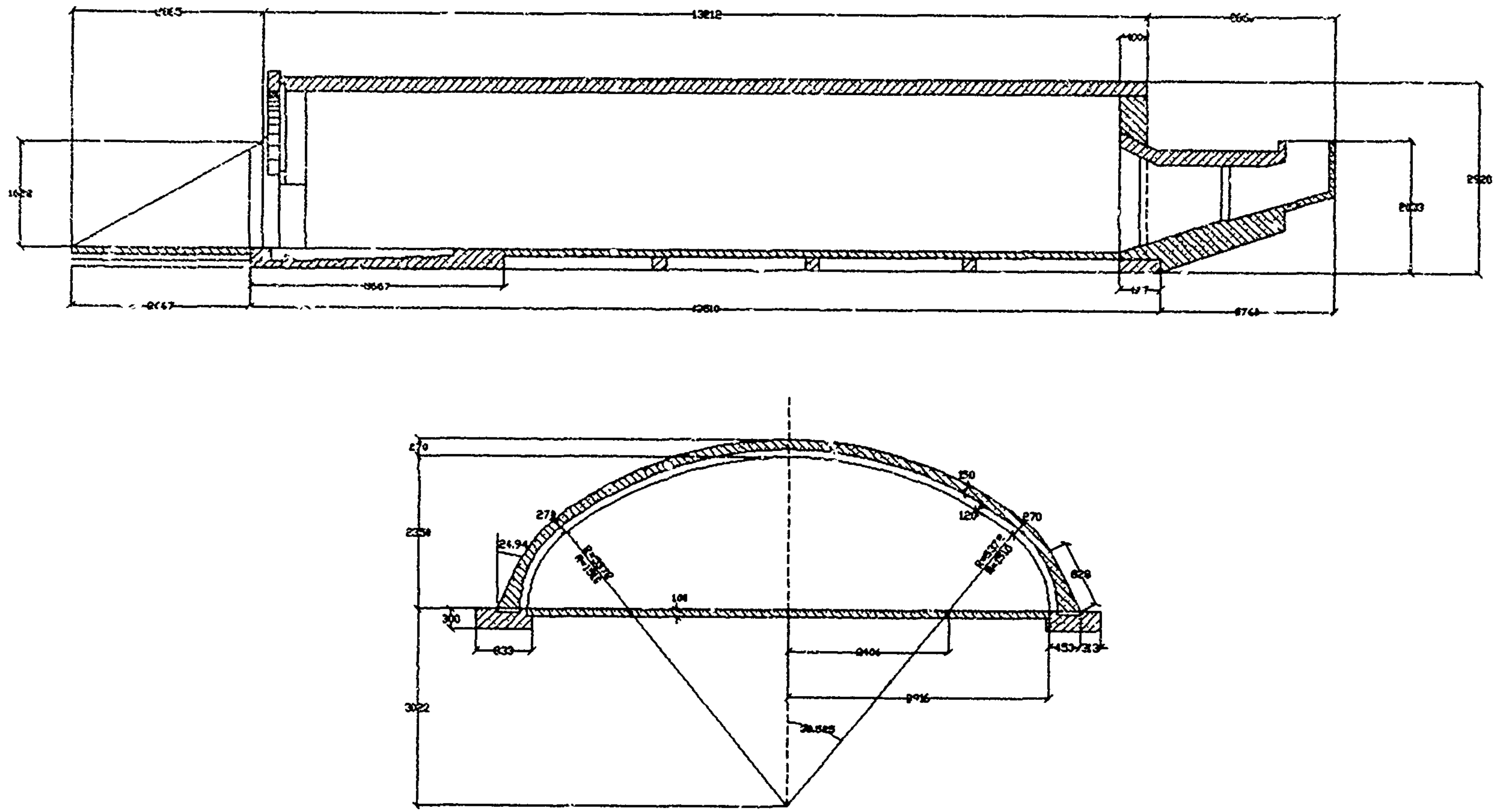
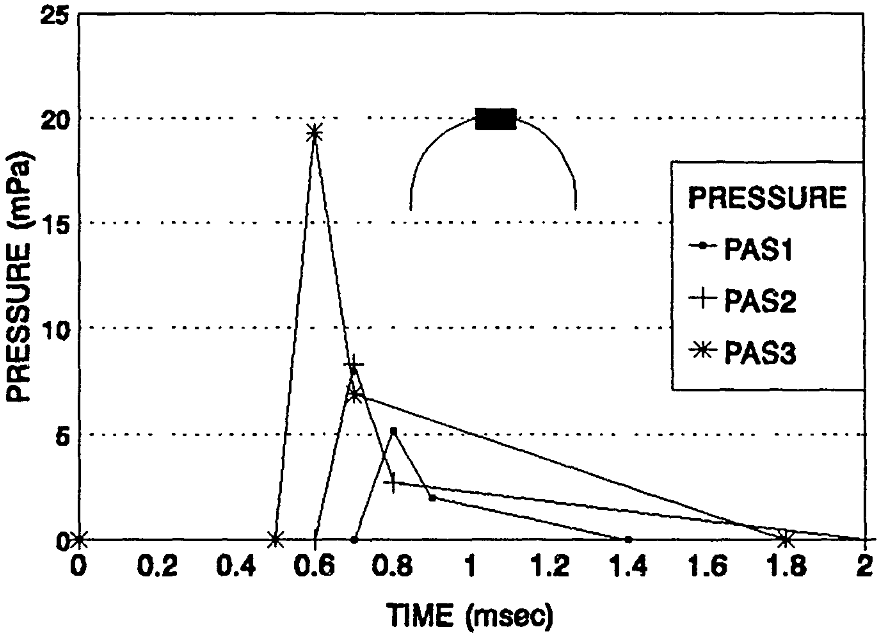


Figure 1. Schematic of Norwegian/US Aircraft Shelter

Pressure Input at Crown



Pressure Input at Middle

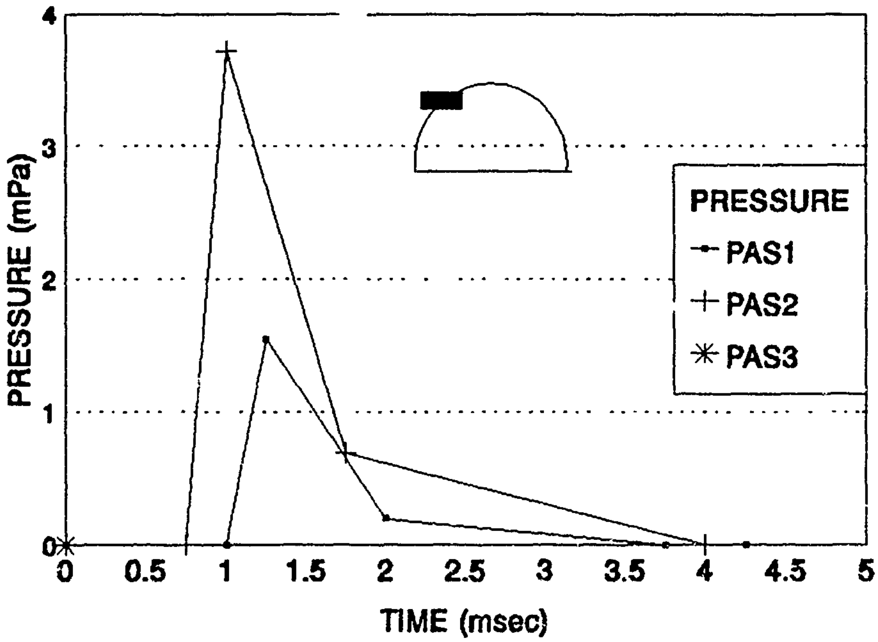


Figure 2. Pressure time histories

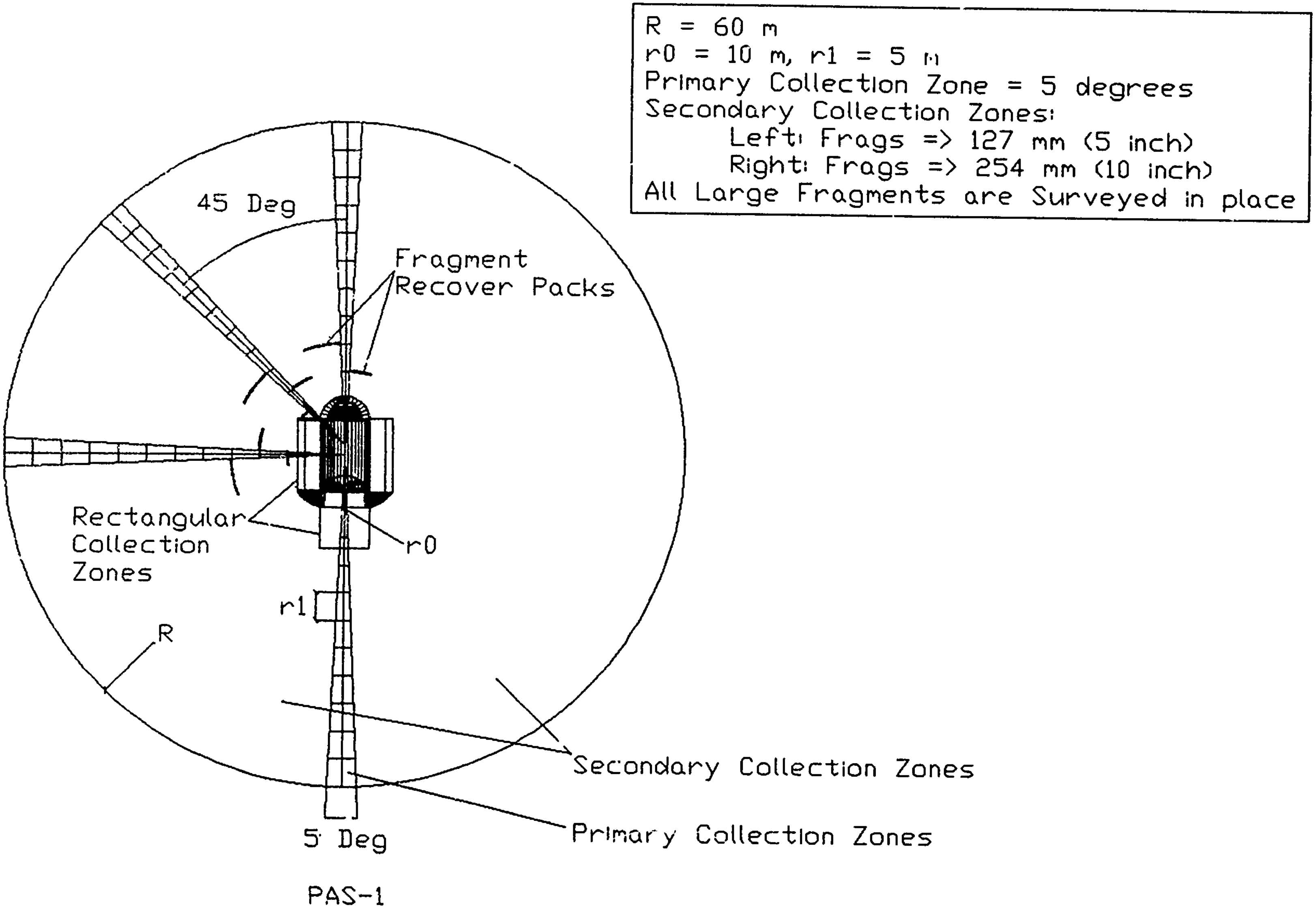


Figure 3: Debris Collection Plan

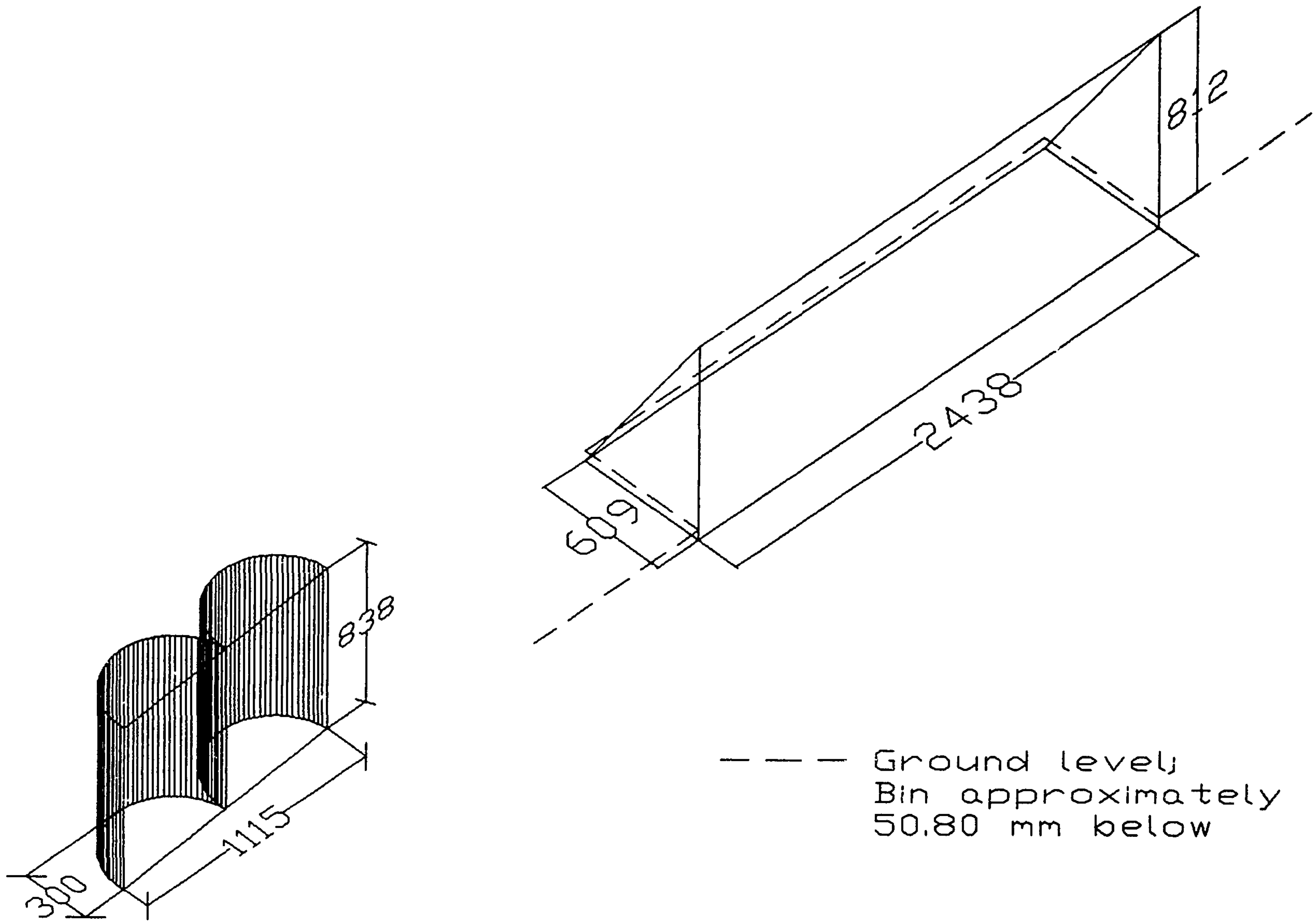


Figure 4: Fragment Recovery Packs

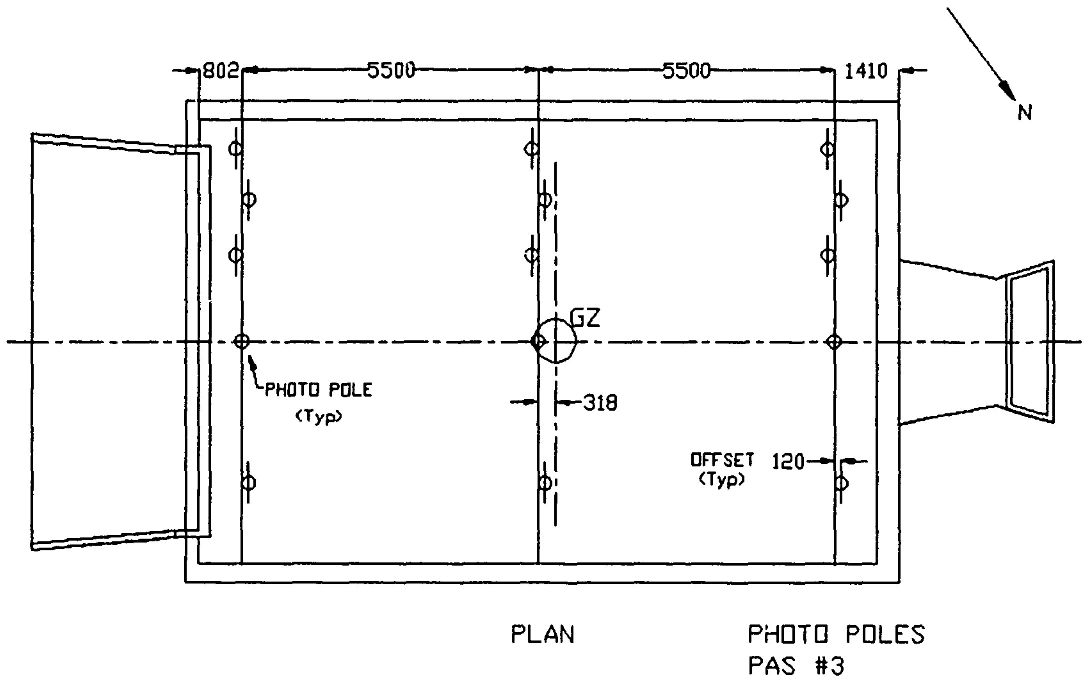


Figure 5: Photo Pole Placement Plan View

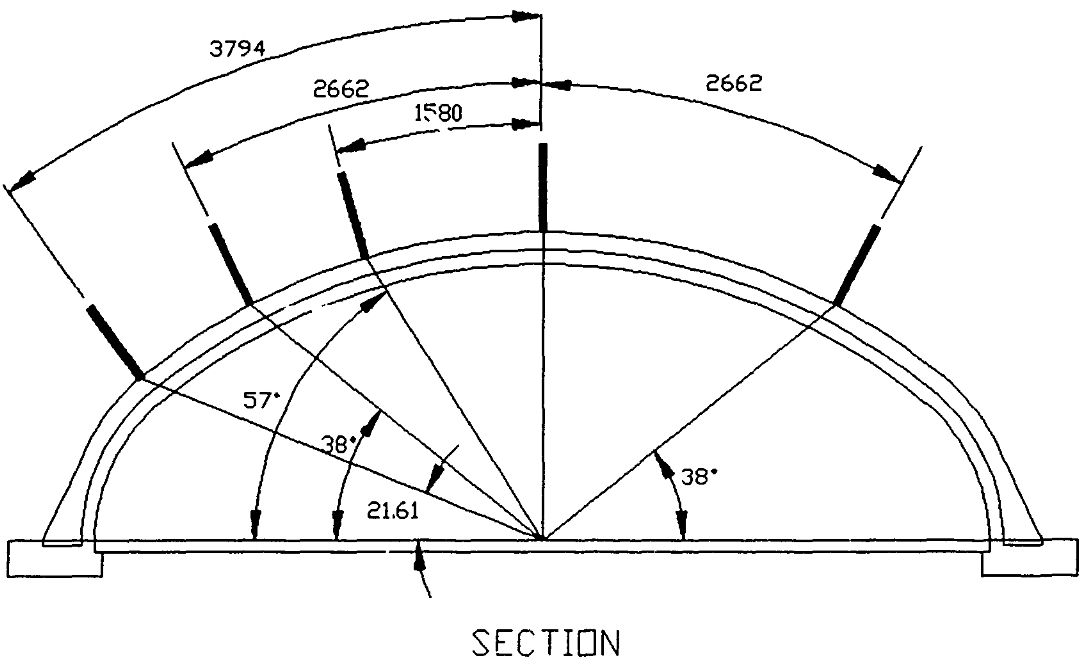


Figure 6: Photo Pole Placement Section View

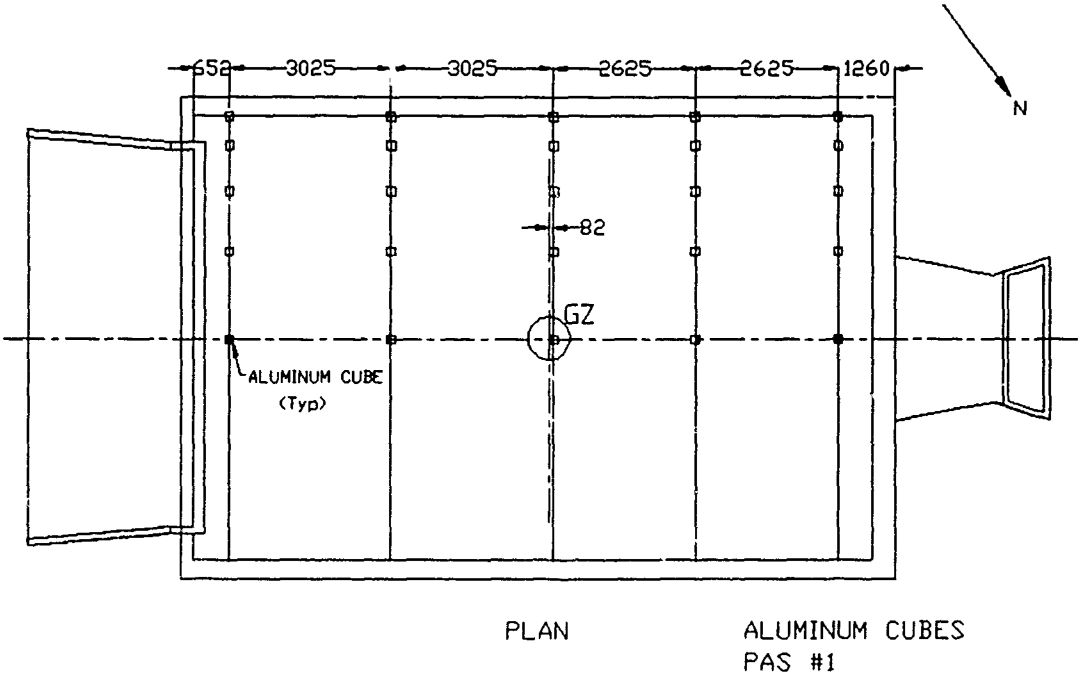


Figure 7: Aluminum Cube Placement Plan View

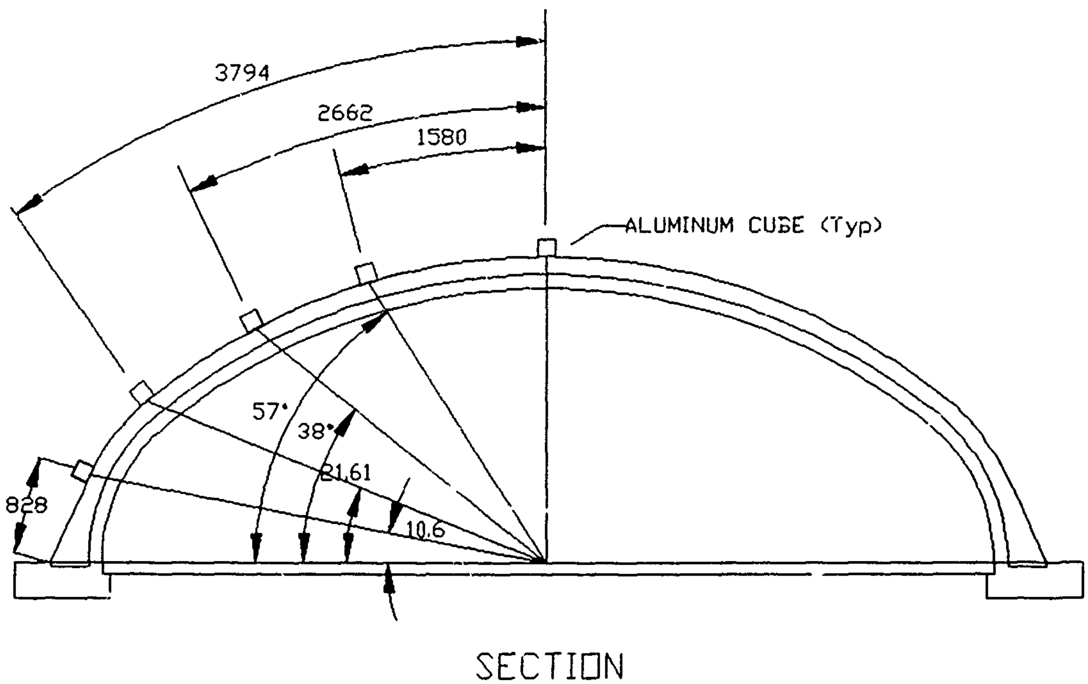


Figure 8: Aluminum Cube Placement Section View

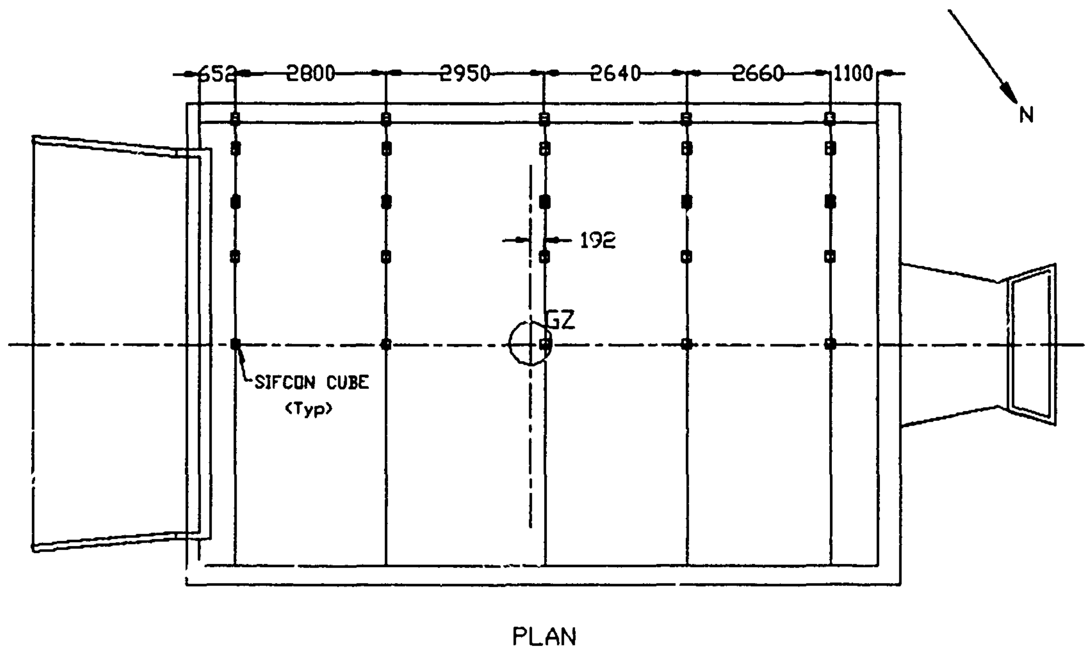


Figure 9: Sifcon Cube Placement Plan View

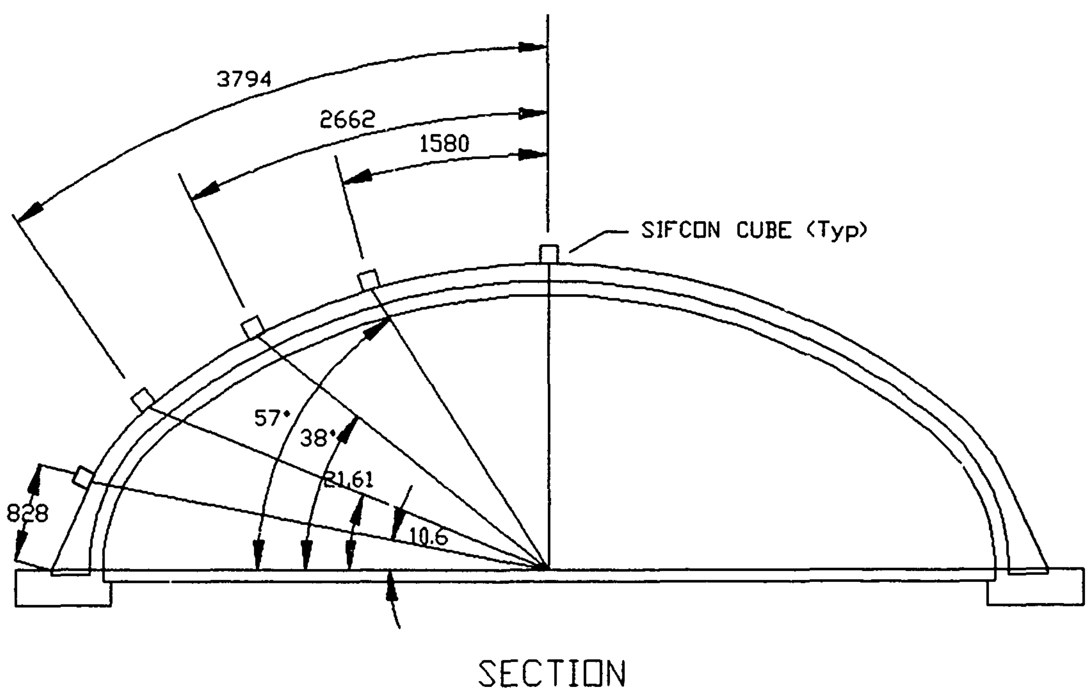


Figure 10: Sifcon Cube Placement Section View

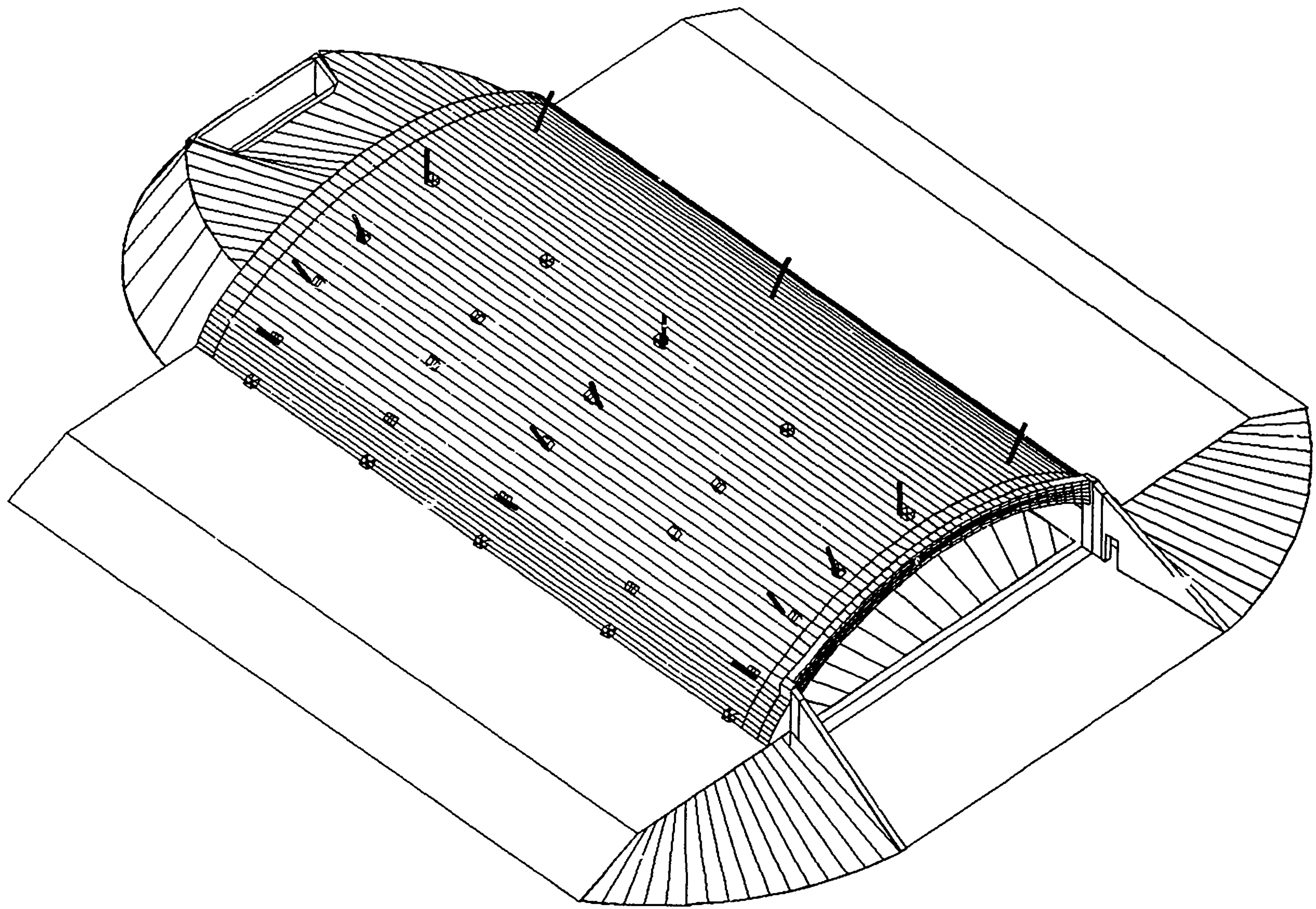


Figure 11: Sifcon Cube Placement Ortho View

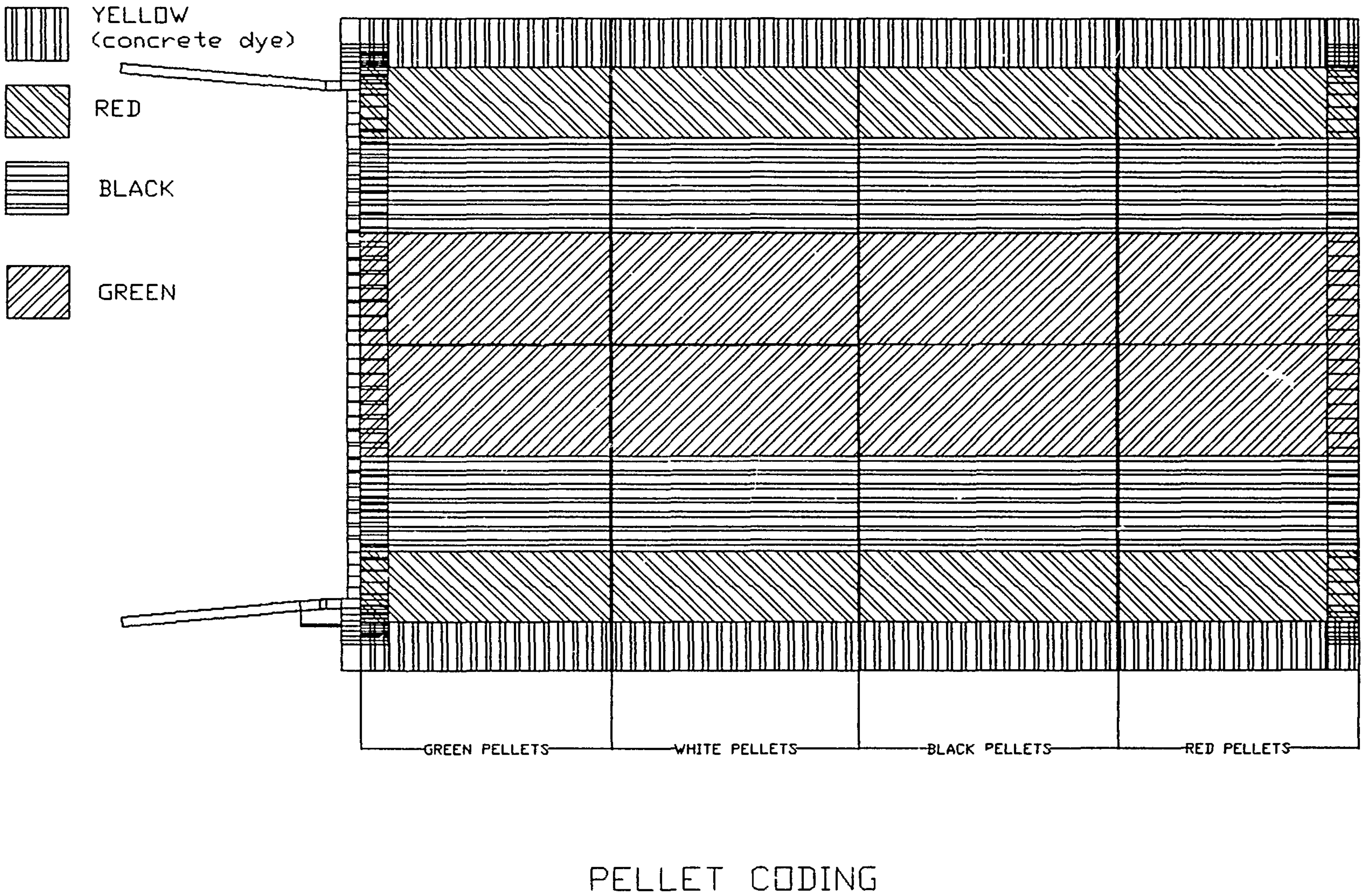


Figure 12: Arch Color Coding

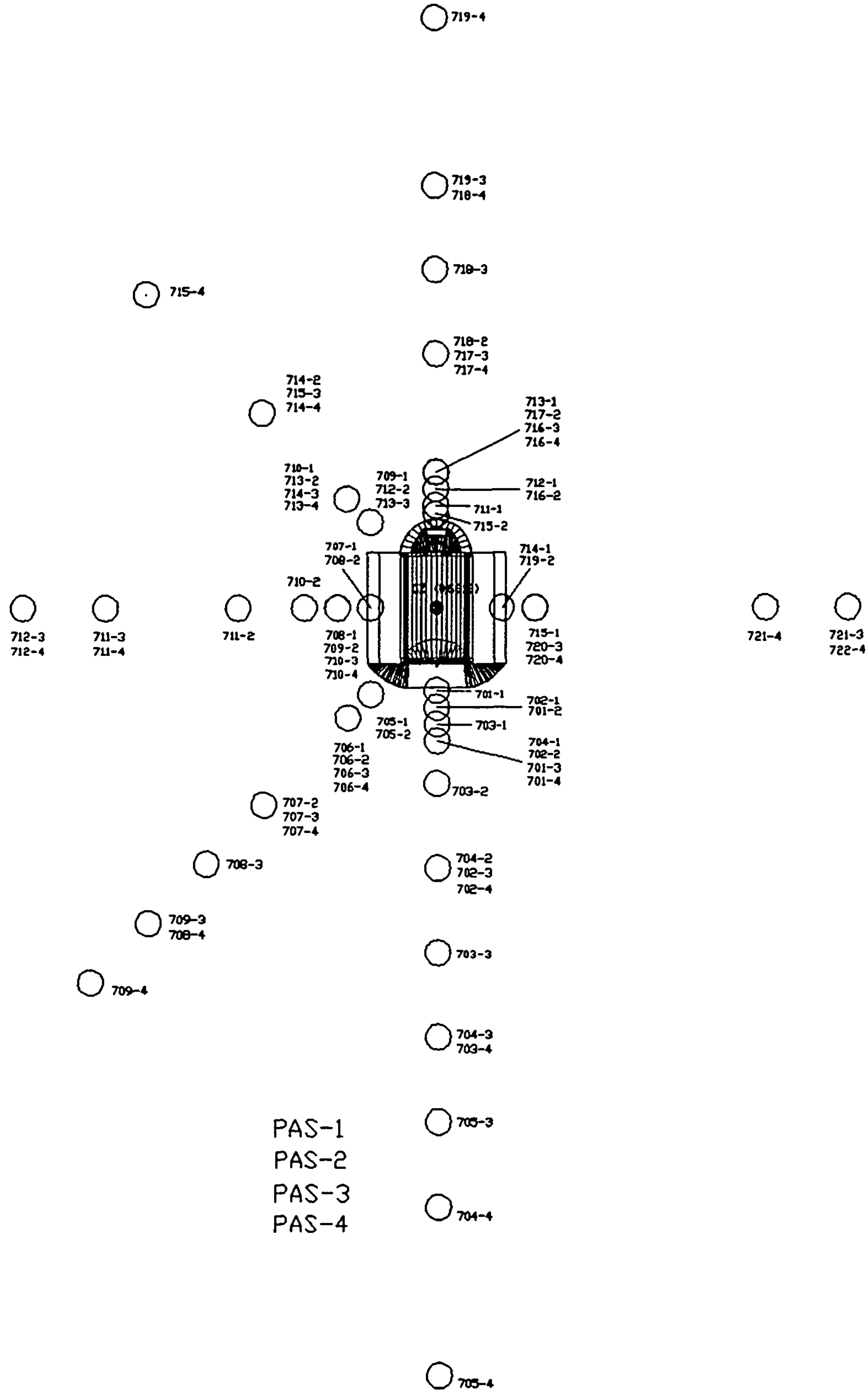


Figure 13: Free Field Gage Map

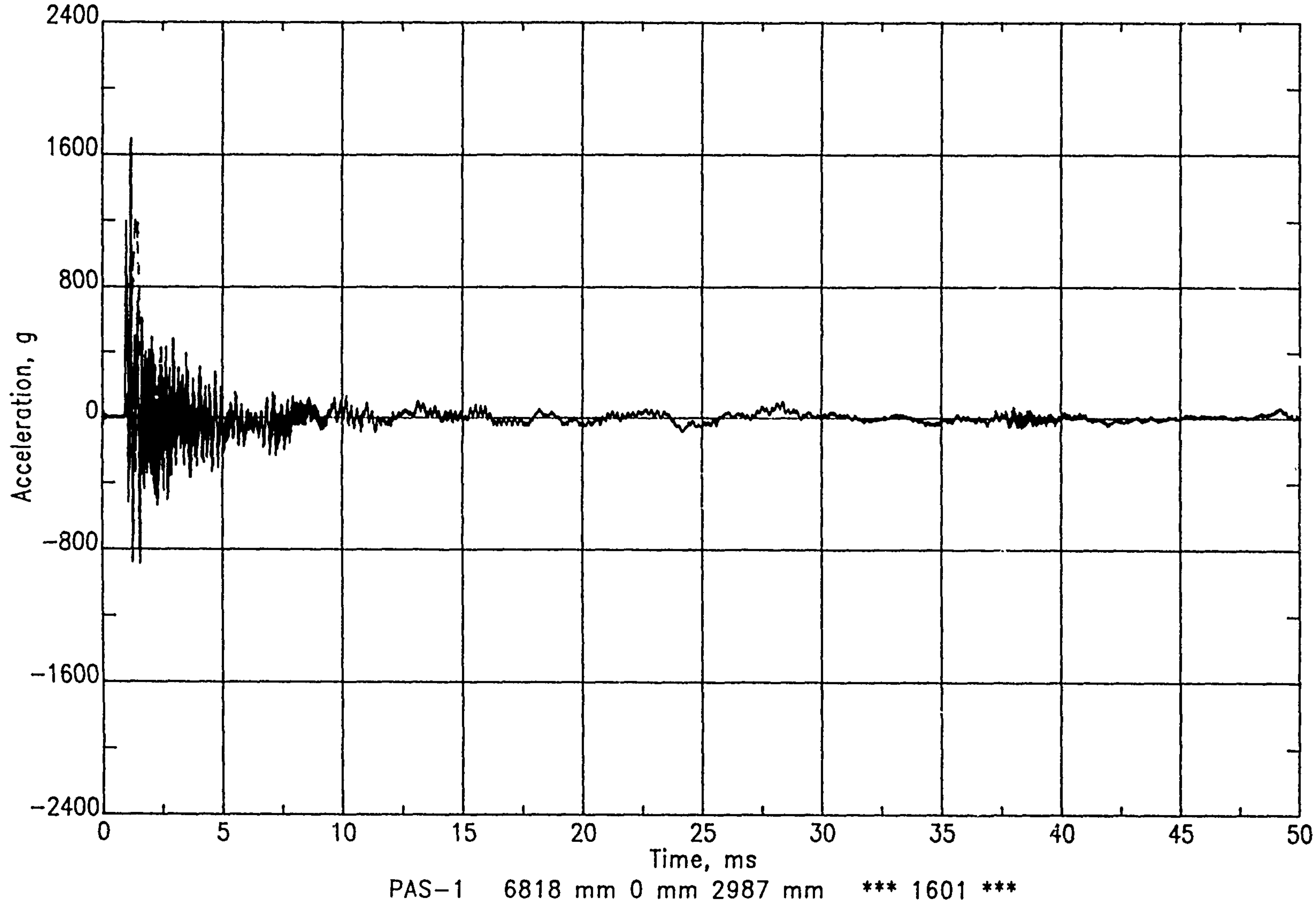


Figure 14: PAS-1 Predicted vs Recorded Accelerations

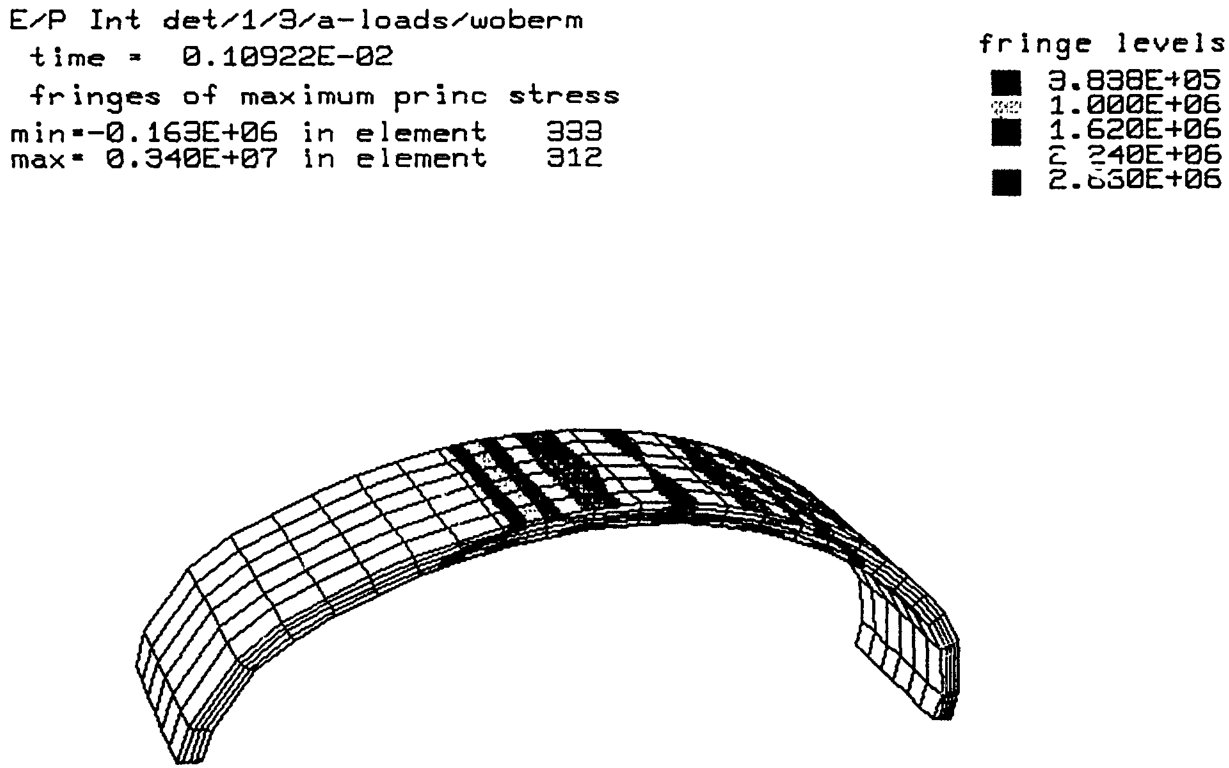


Figure 15: PAS-1 Maximum Principal Stress

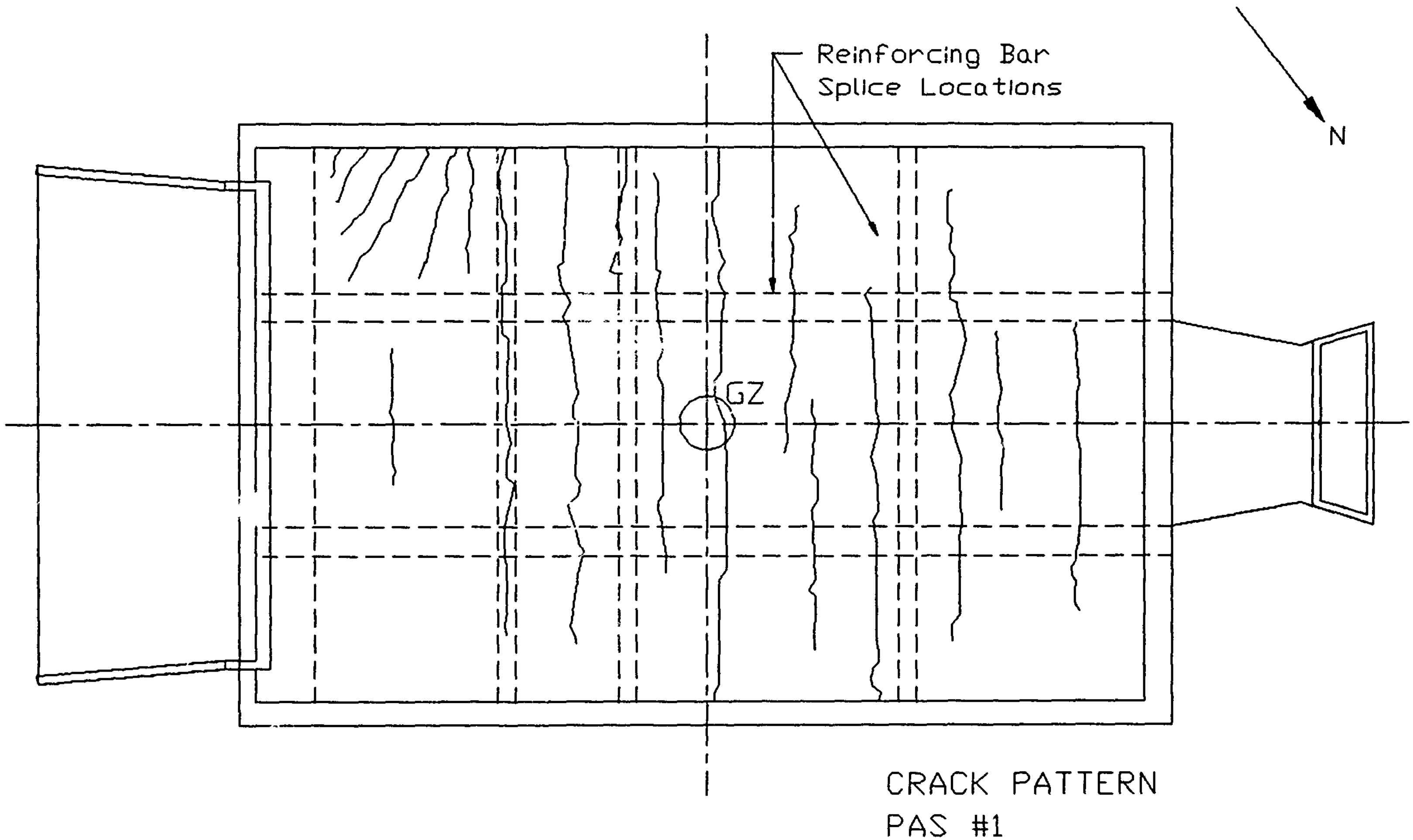


Figure 16: PAS-1 Arch Crack Pattern

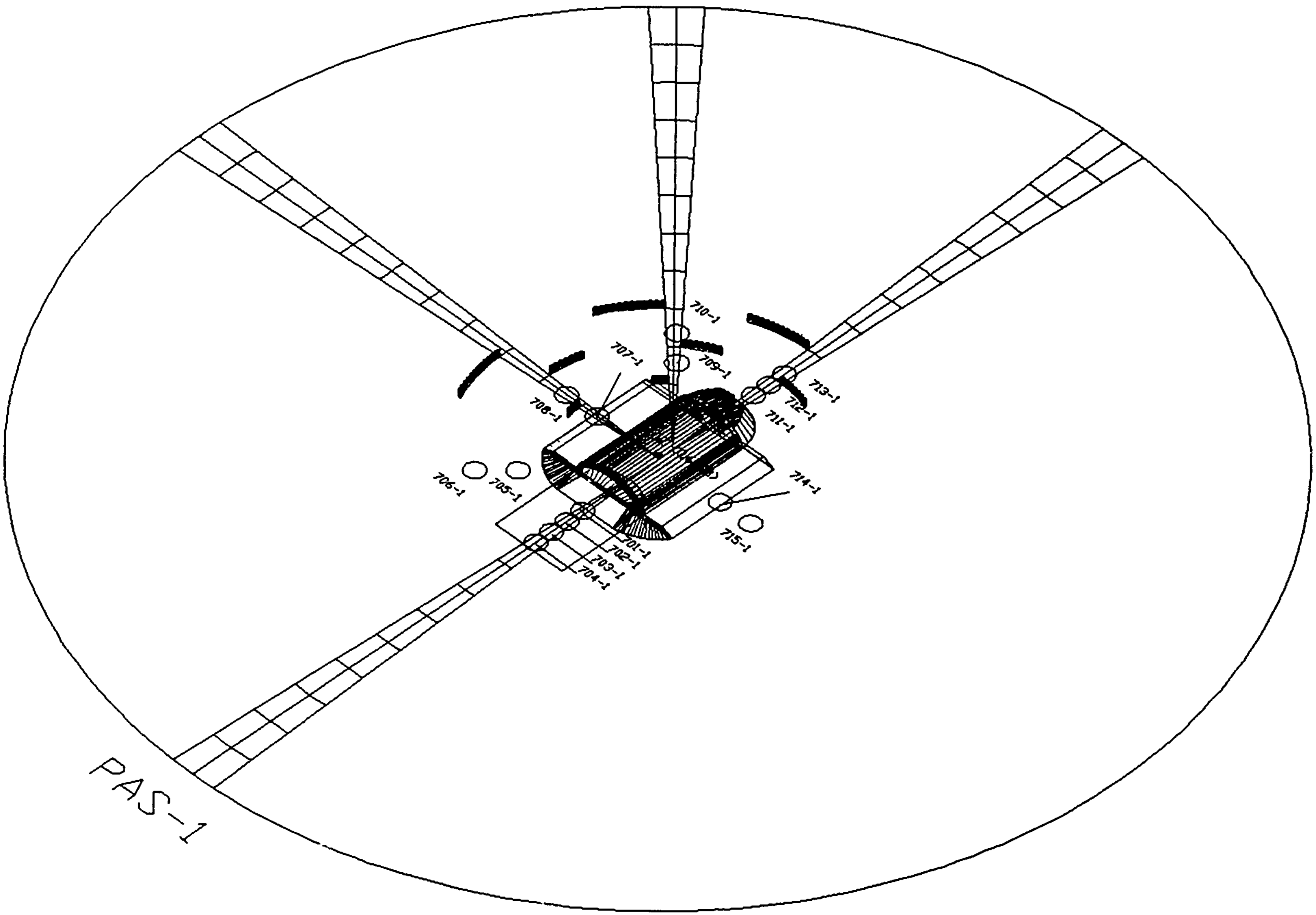


Figure 17: PAS-1 Test Bed Layout

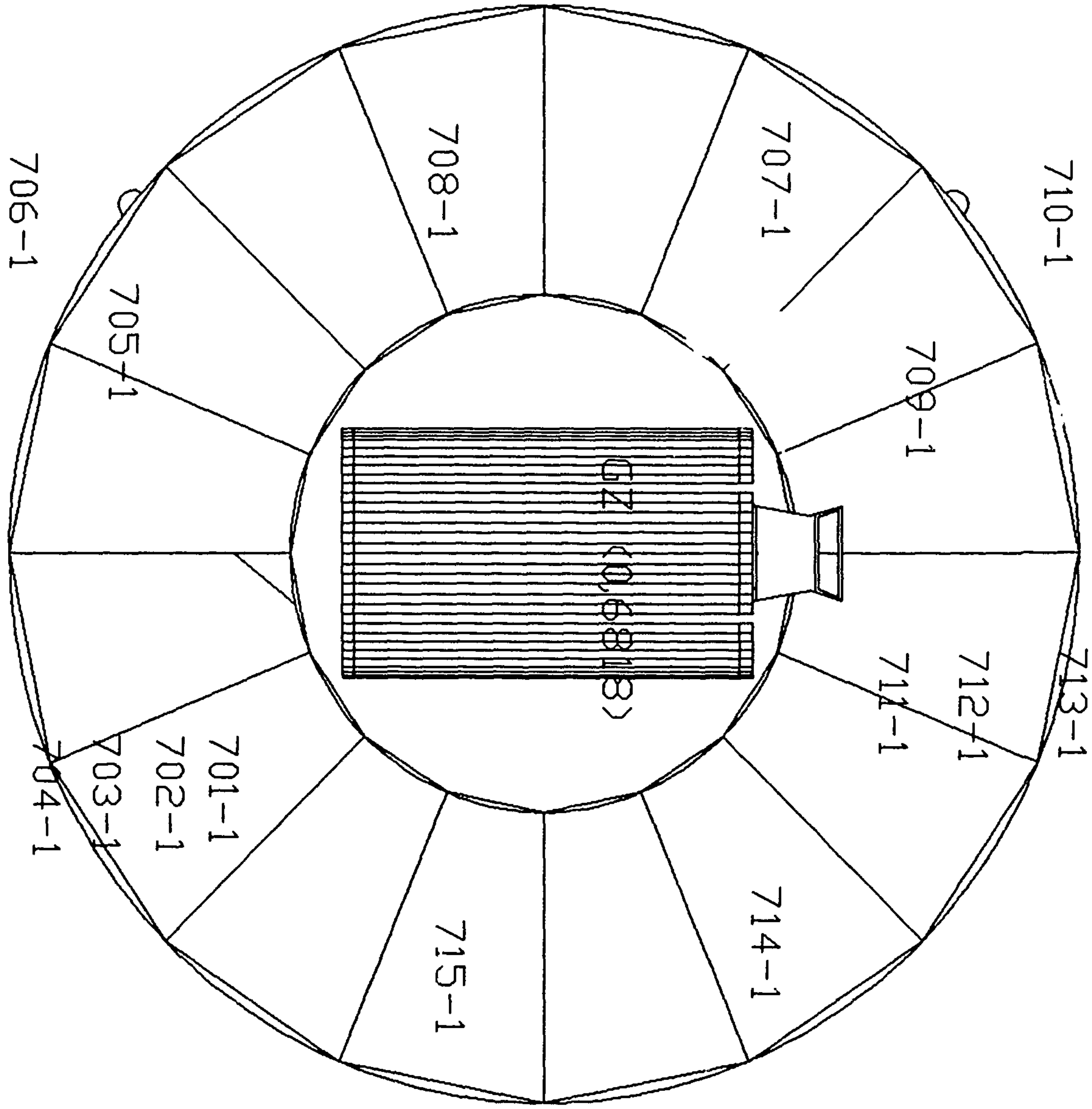


Figure 18: PAS-1 One PSI Contour

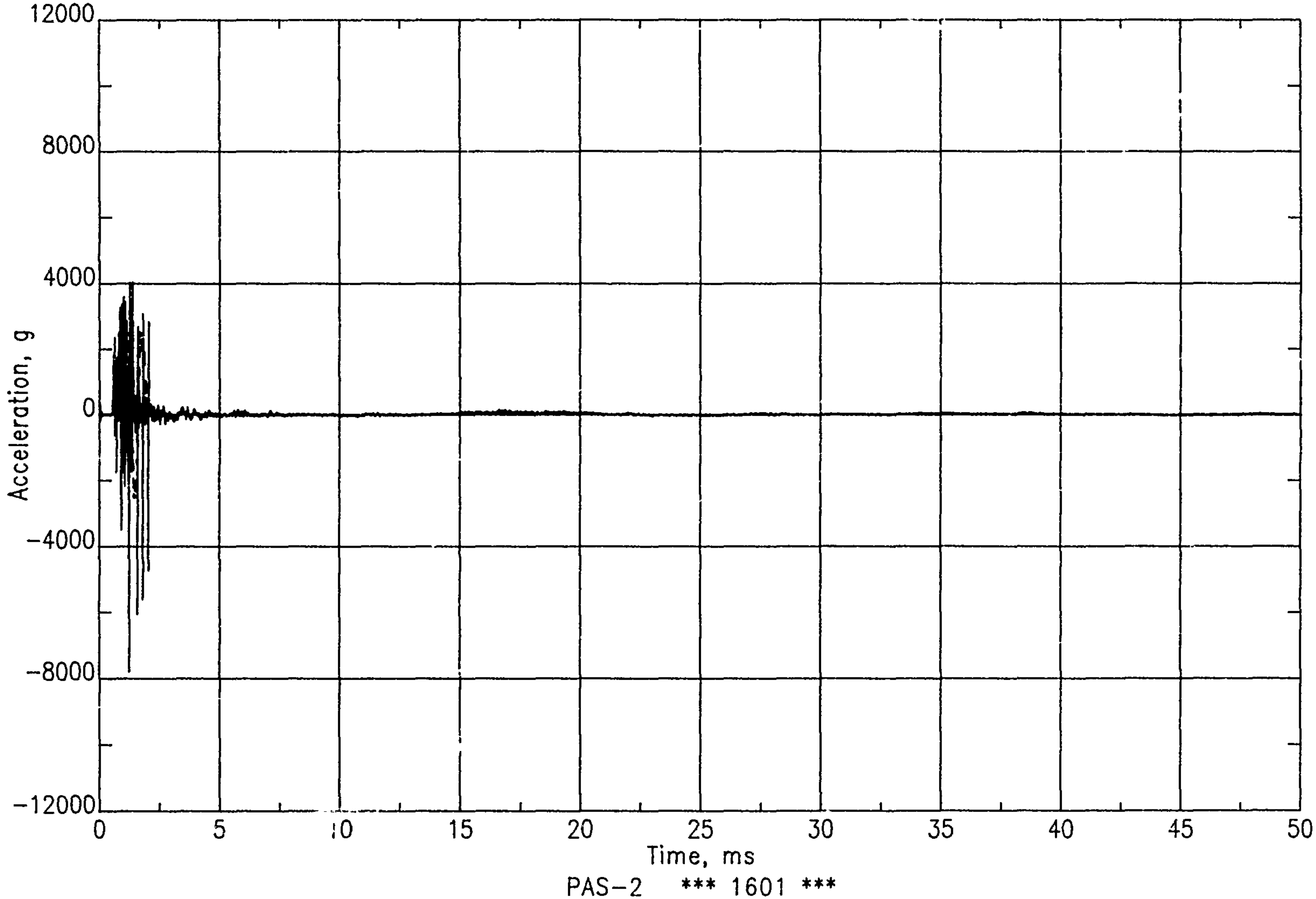


Figure 19: PAS-2 Predicted vs Recorded Accelerations

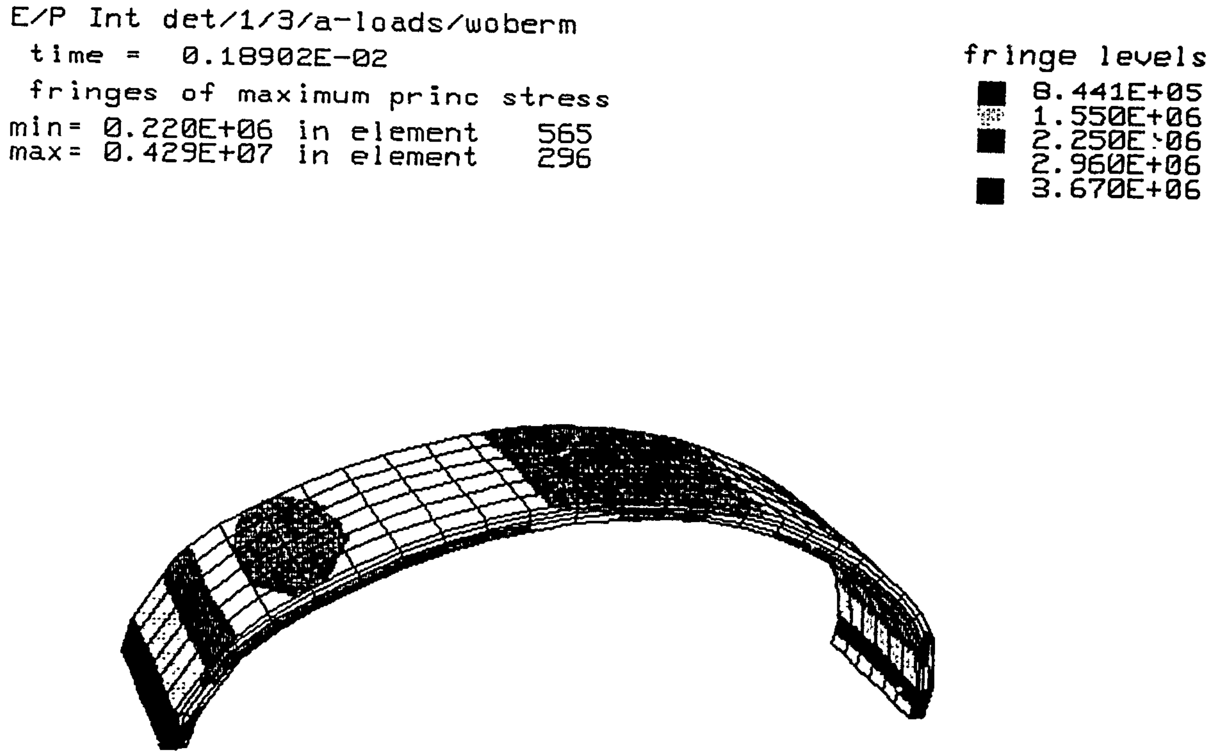


Figure 20: PAS-2 Maximum Principal Stress

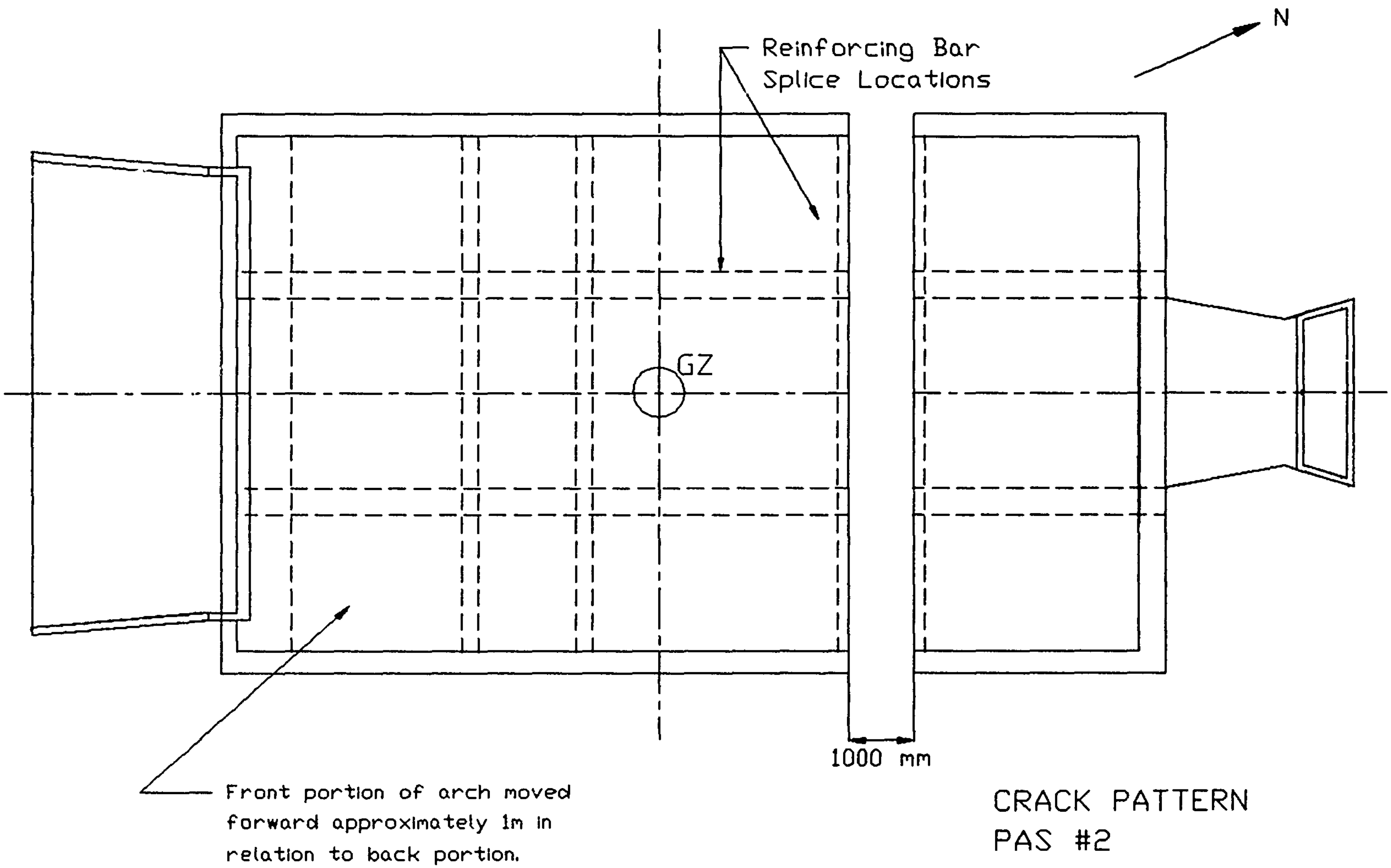


Figure 21: PAS-2 Arch Crack Pattern

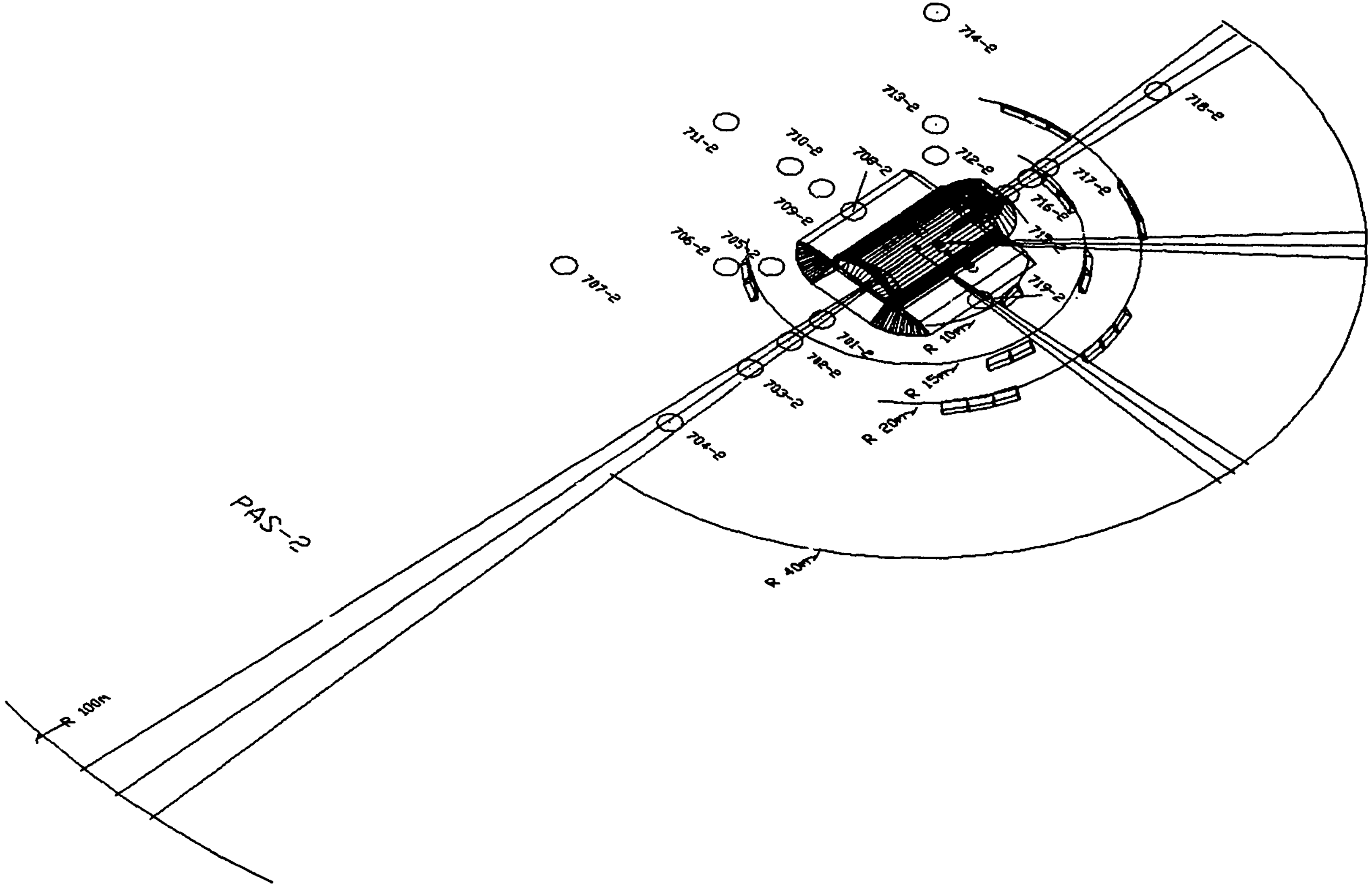


Figure 22: PAS-2 Test Bed Layout

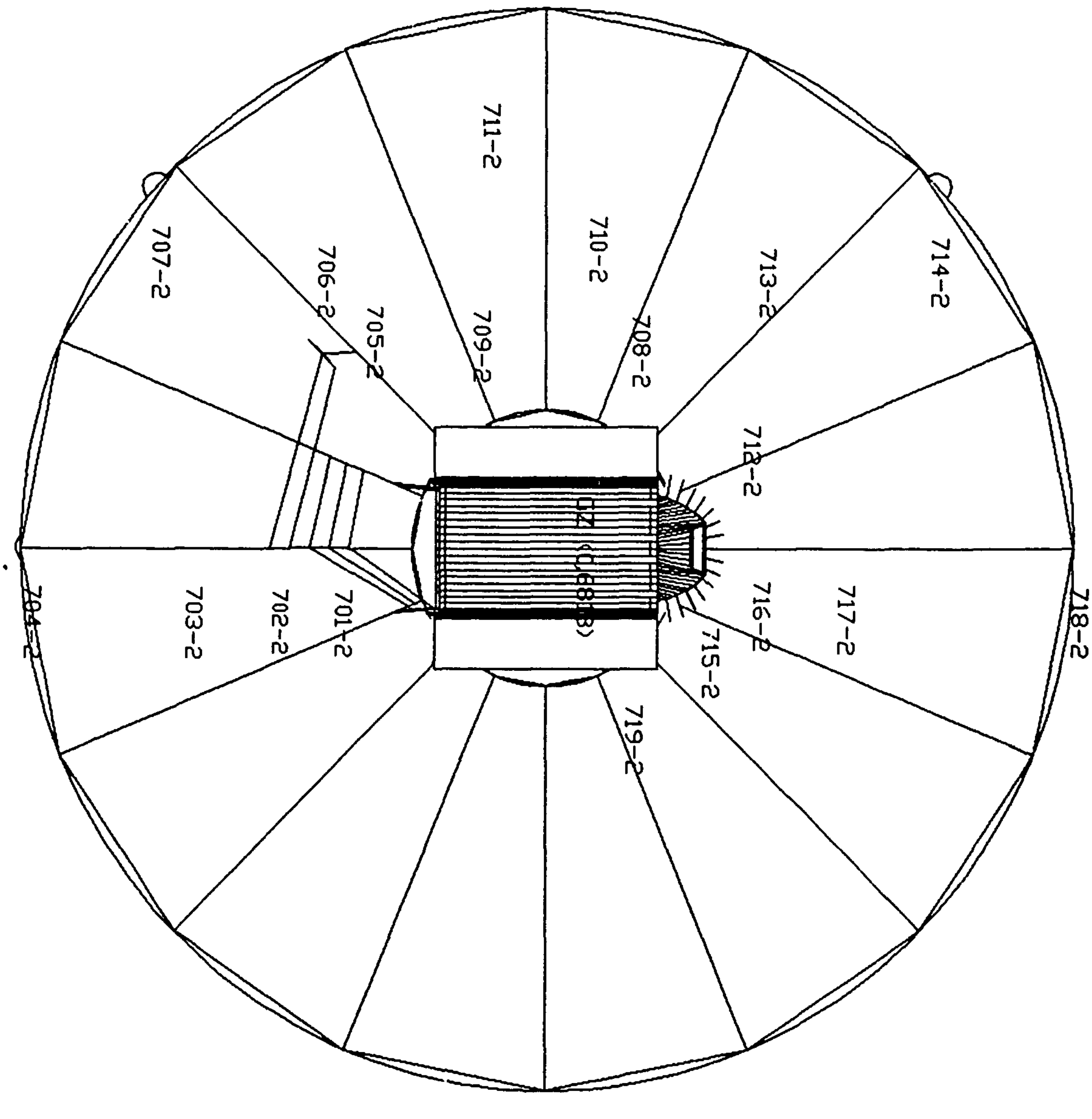


Figure 23: PAS-2 One PSI Contour

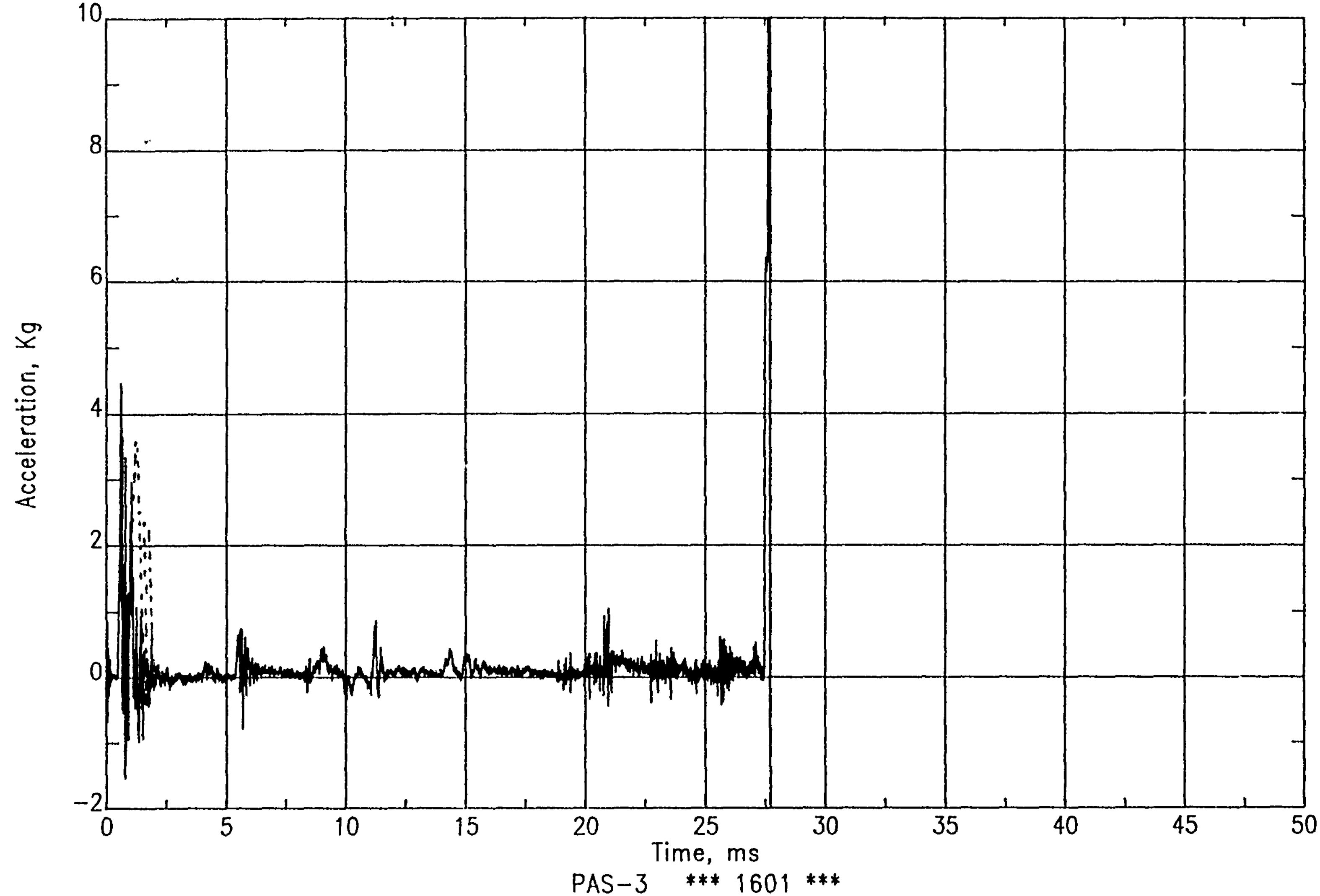


Figure 24: PAS-3 Predicted vs Recorded Accelerations

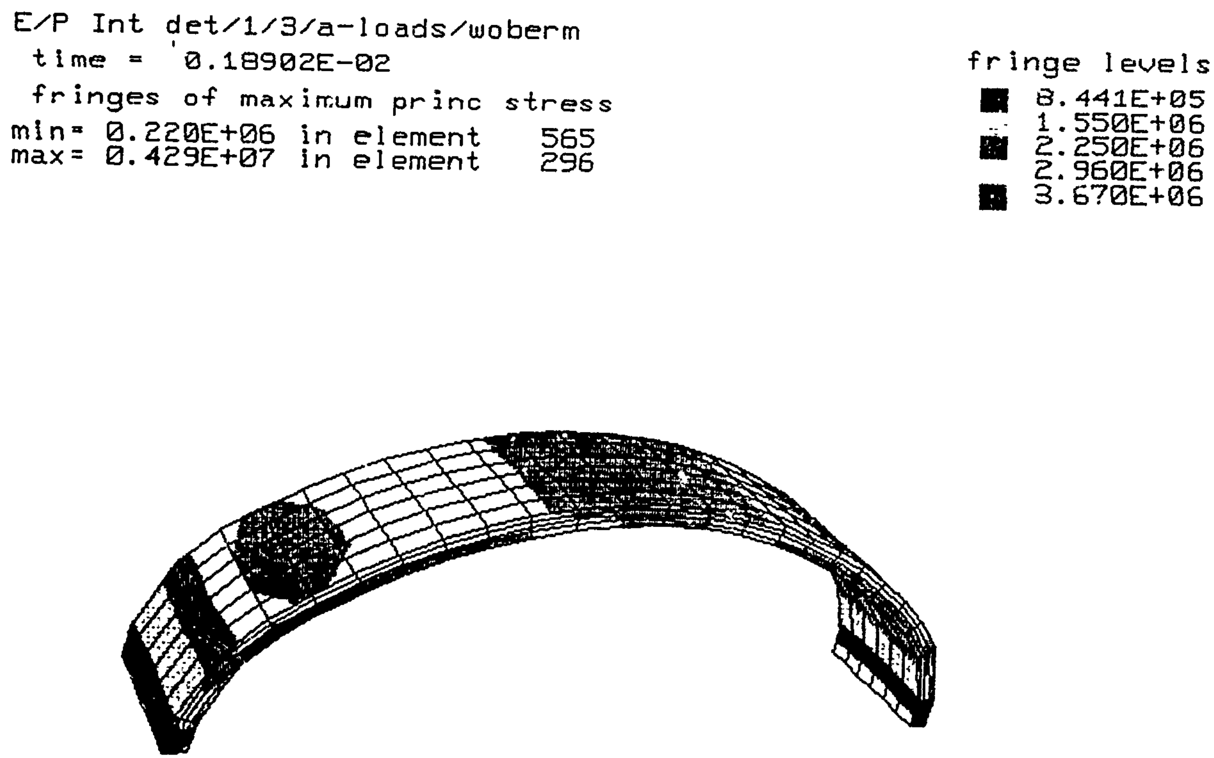


Figure 25: PAS-3 Maximum Principal Stress

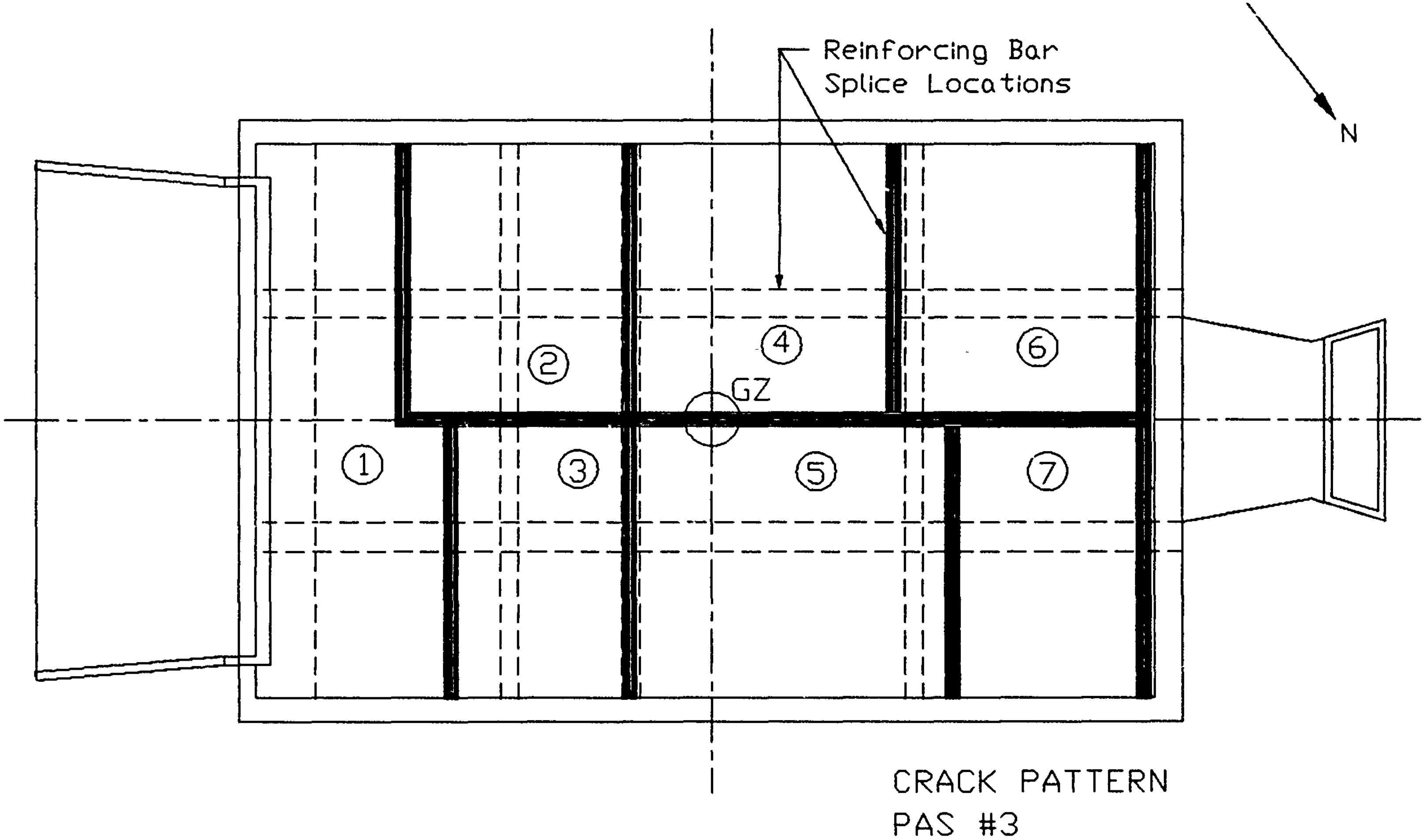


Figure 26: PAS-3 Arch Crack Pattern

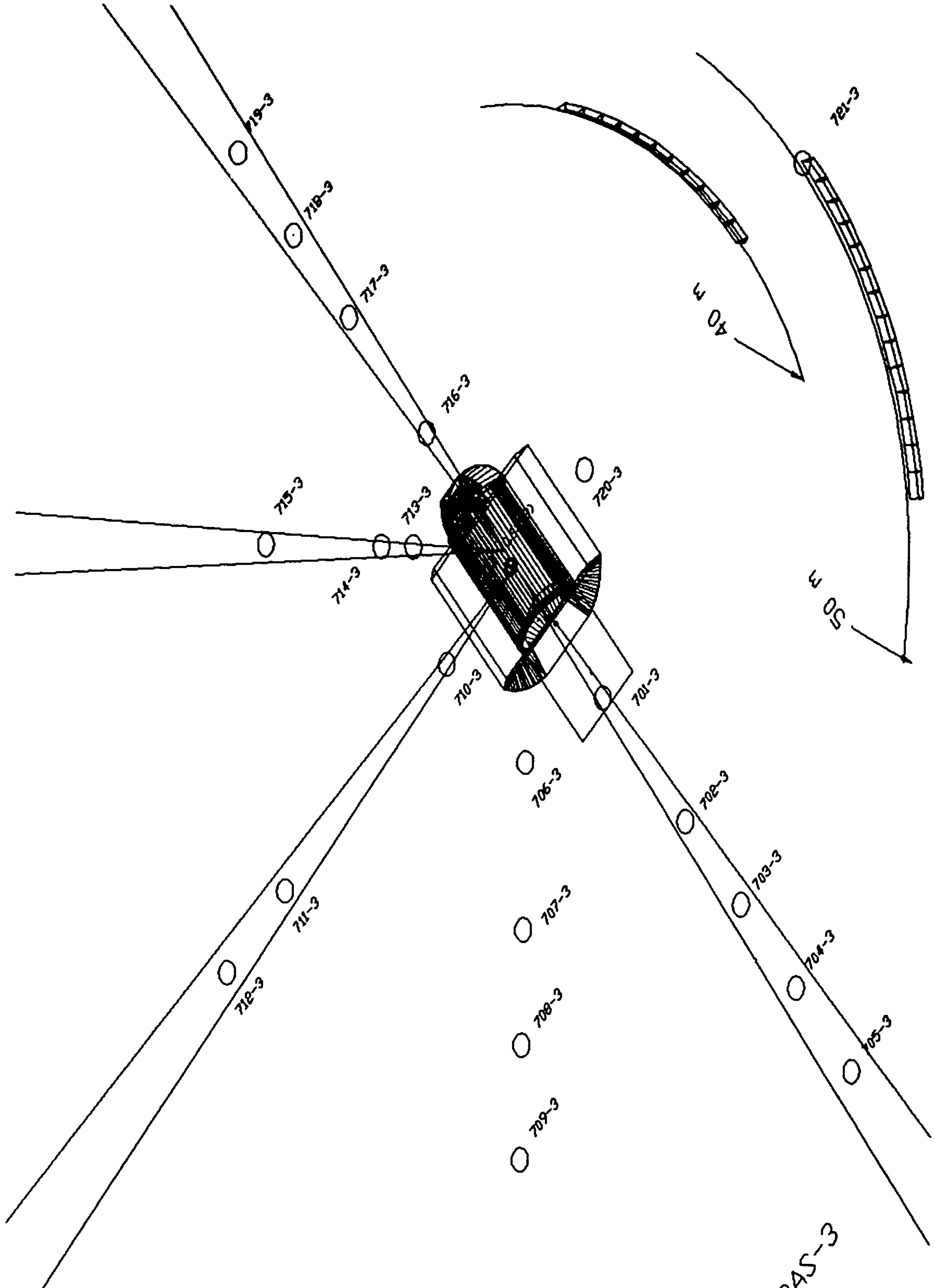


Figure 27: PAS-3 Test Bed Layout

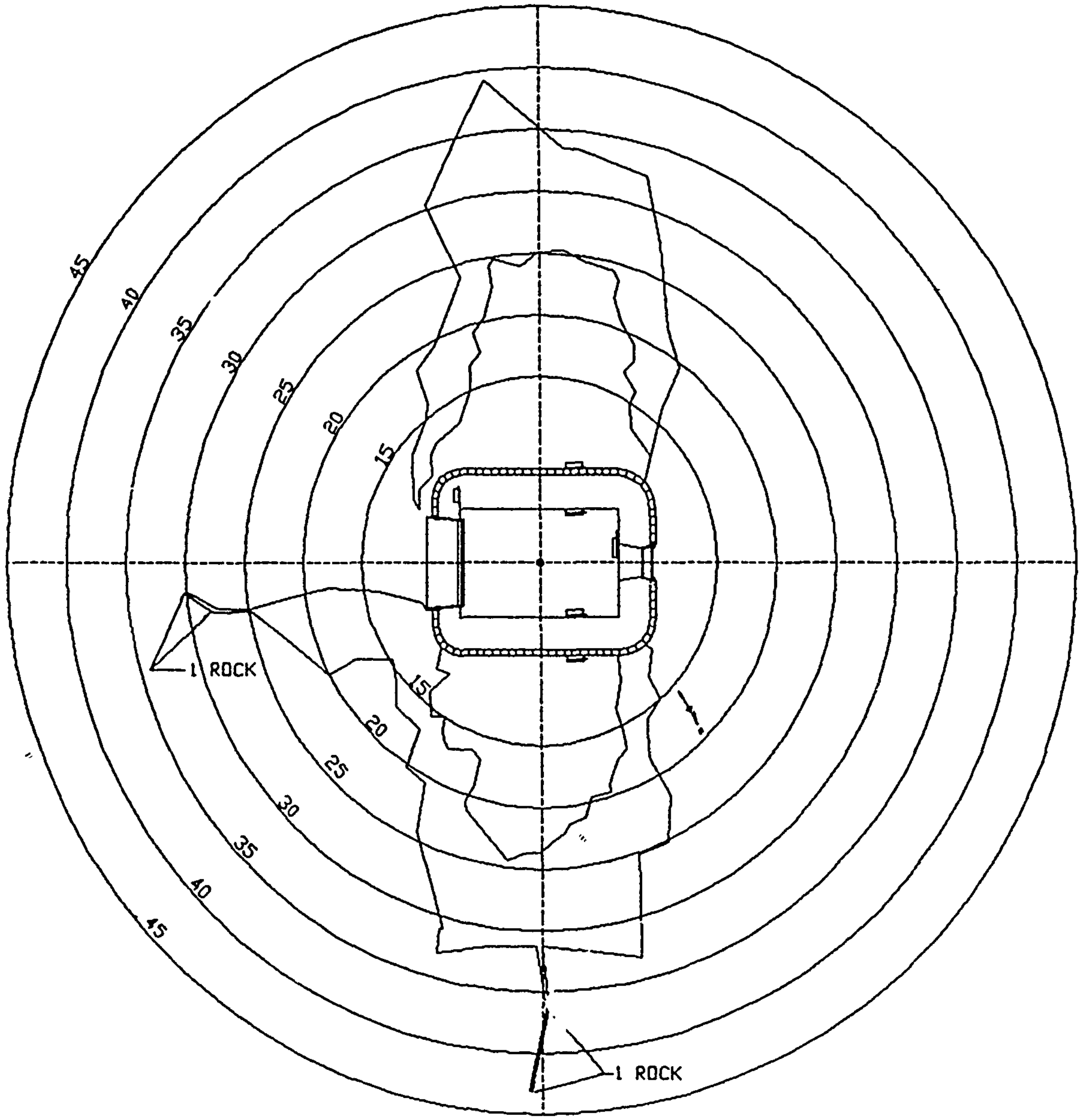


Figure 28: PAS-3 Rock Ruble Distribution Map

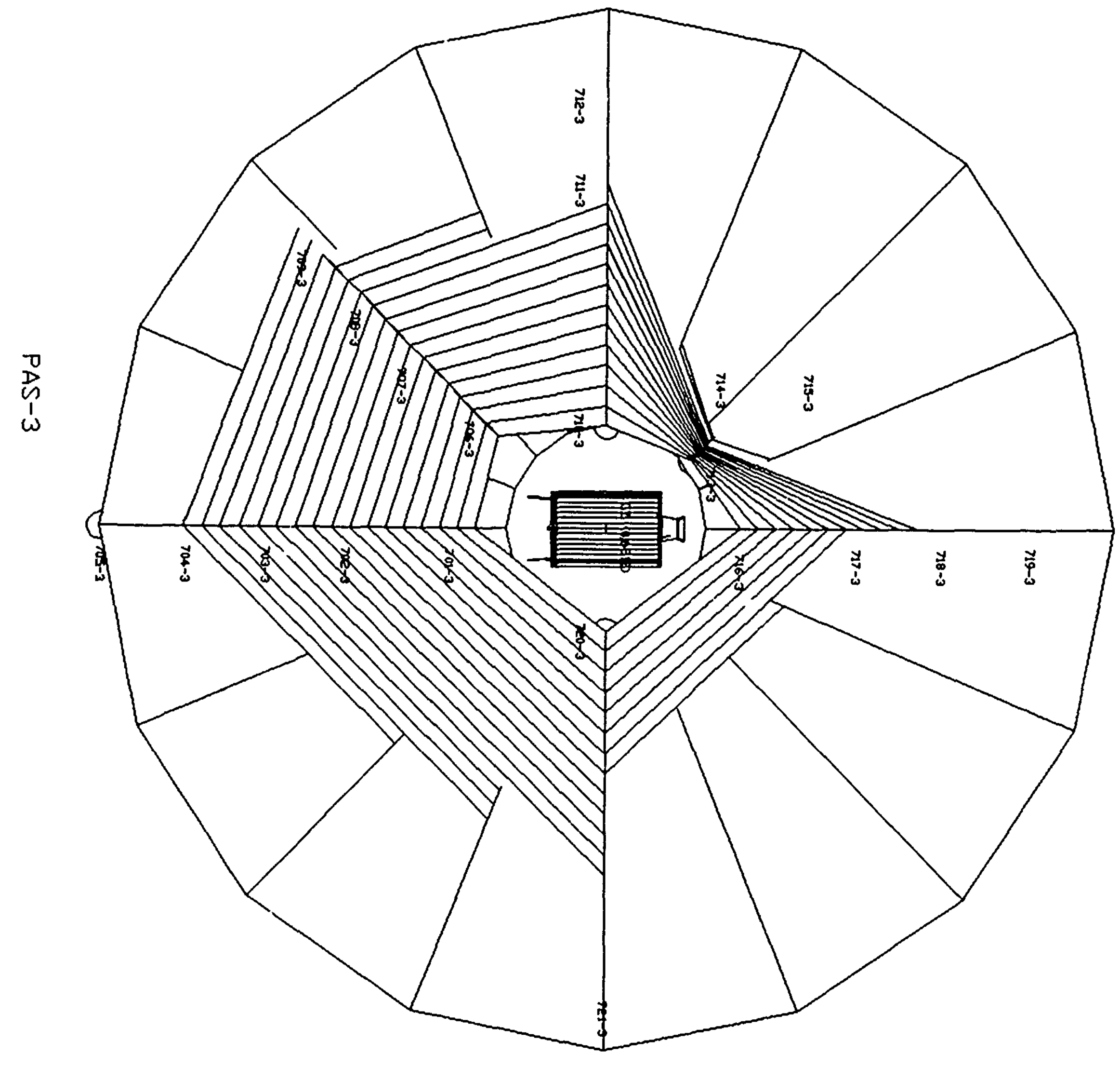


Figure 29: PAS-3 One PSI Contour

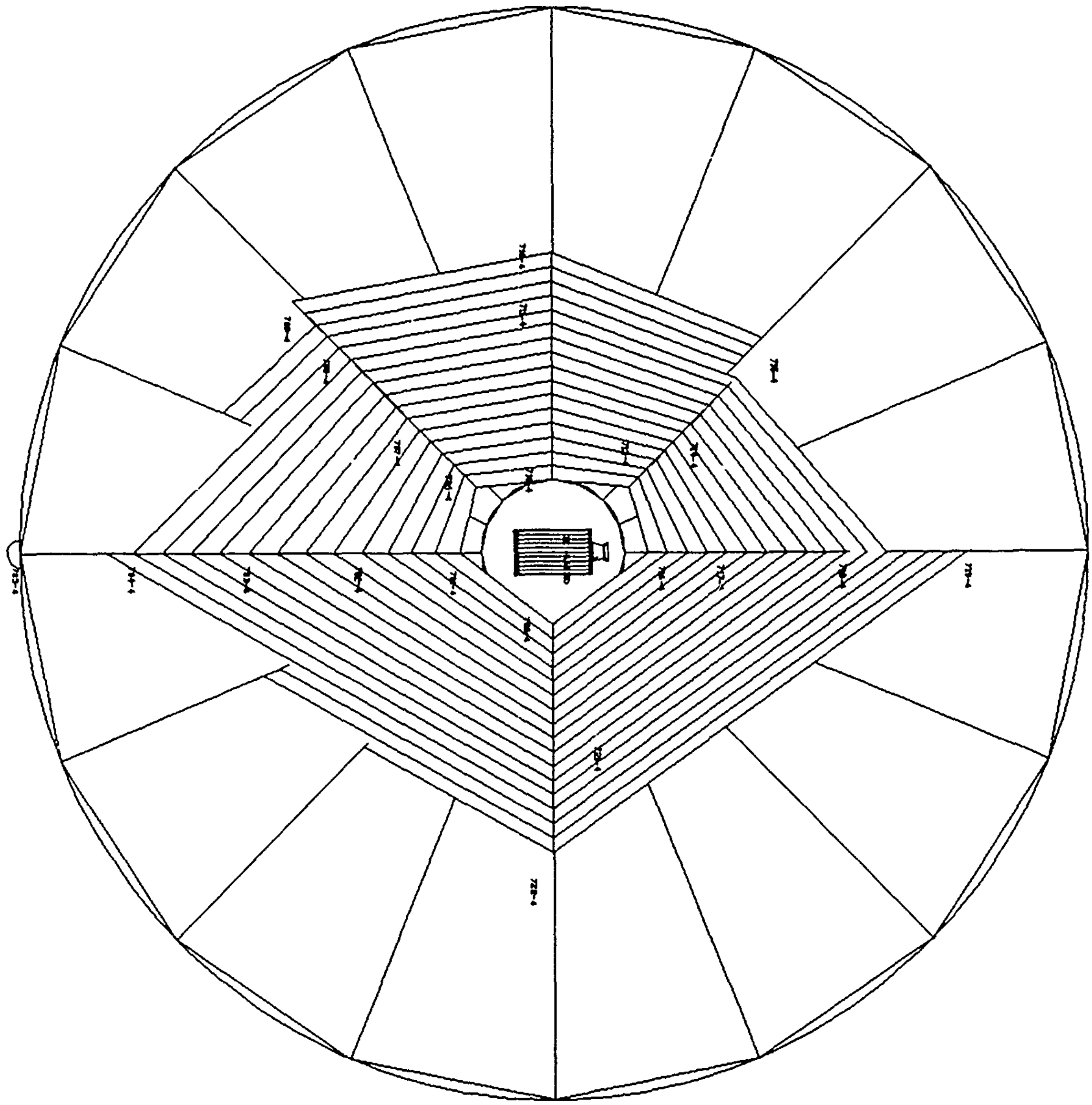


Figure 30: PAS-4 One PSI Contour

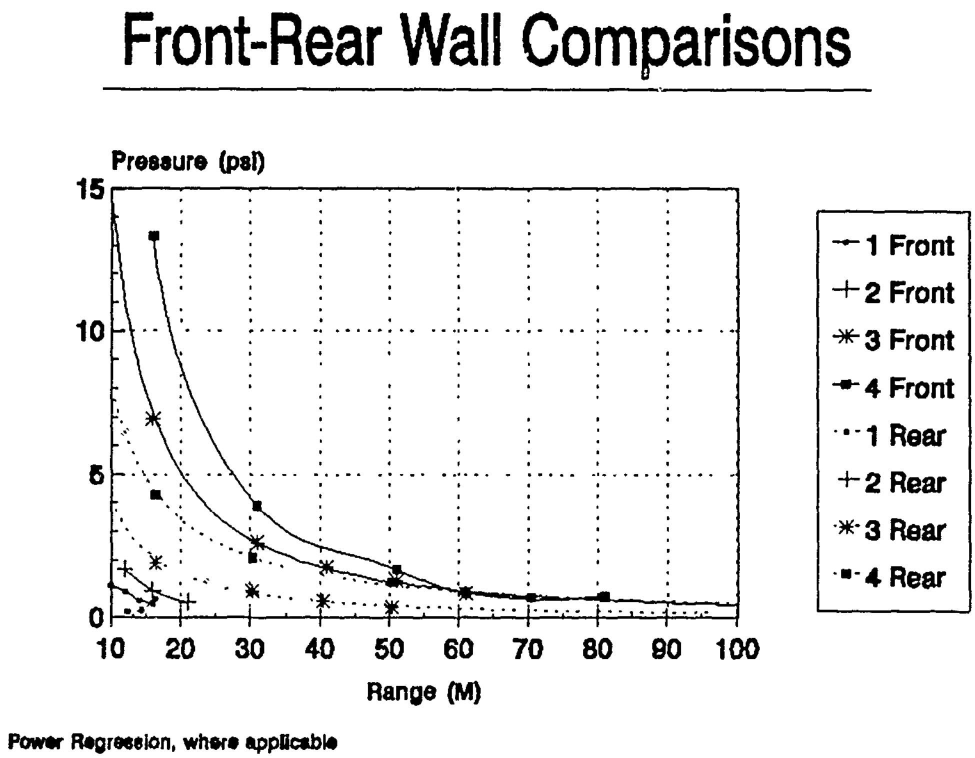


Figure 31: Static Overpressure Front and Rear Wall

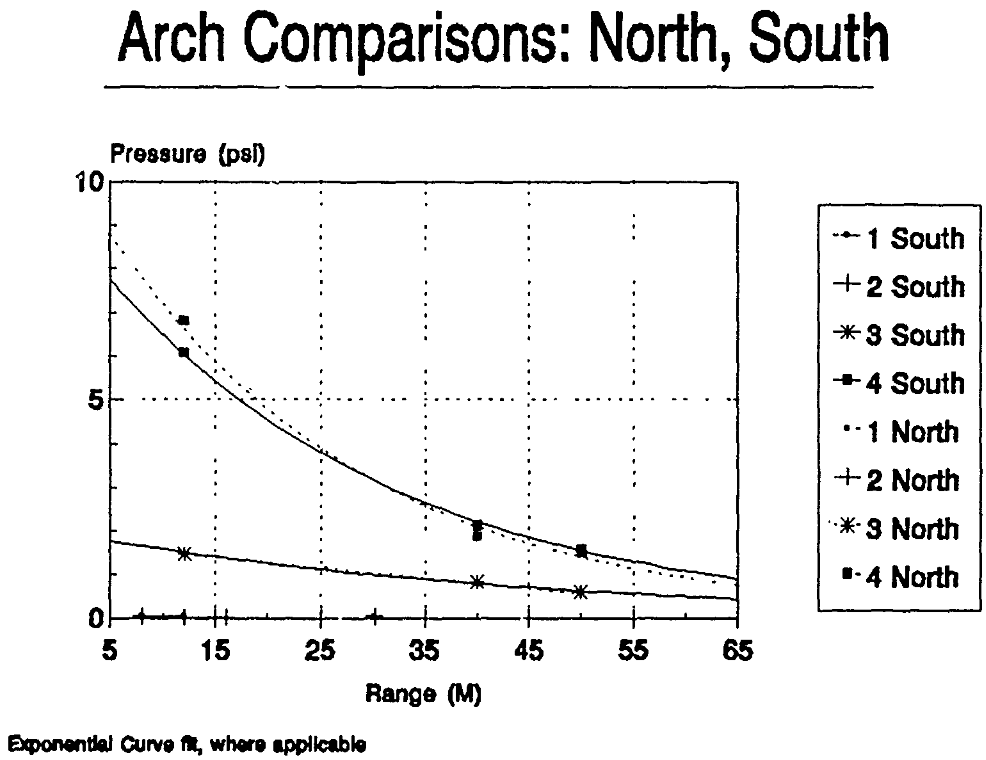


Figure 32: Static Overpressure Arch and 45° Radial

Numerical Calculations of Explosive Charges Inside Scaled Aircraft Shelters

Robert W. Robey

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Introduction

The modeling of small explosive charges or conventional weapons offers a surprising challenge to the numerical modeler. These problems almost always require 3D geometry and the very short duration peaked waveforms demand small cell sizes. The result is that these problems push the limits of computer memory and speed.

The subject of the calculations discussed in this paper were a set of experiments conducted to examine and study the effects of bare explosive charges inside an aircraft shelter. Three distinct phases were done for each calculational effort.

First, prior to the tests, a numerical simulation of the explosive event was done to determine what pressure ranges to set for the pressure instrumentation and to provide pressure input for the structural modeling.

Immediately after the test event, comparisons of experimental data and the calculation were done to confirm a good test and to detect possible problems with experimental records.

Post-test, adjustments to the calculational model were made to improve the calculational results. Besides the obvious improvement in predictive ability, this process generates a greater understanding of what experimental parameters are important and a greater understanding of the phenomenology that occurs as a blast propagates through the interior of the aircraft shelter.

Description of NMERI Hydrocodes

The NMERI GUSH (GenUinely Simple Hydrocode) program is a positively conservative, inviscid, Eulerian hydrocode which supports multiple fluid materials in two-dimensional (2D cartesian and cylindrical) and three dimensional (3D cartesian) geometries. It uses an ideal gas (gamma law) equation of state to relate fluid pressure to density and internal energy for mixtures of materials. It supports arbitrarily selectable transmissive and rigid mesh boundaries as well as input boundaries. Additional capabilities include islands and moving islands which are also called flakes and can move through the mesh to simulate responding or externally driven rigid structures. The code is capable of modeling two-phase (fluid and particle) and reactive (Arrhenius and/or fixed rate) flows. Versions have been run on computer systems ranging from PCs to the Cray 2.

The GUSH finite difference algorithms are very similar to those numerical codes relying on artificial viscosity such as HULL and SHARC. These codes are essentially quasi-second order (second order in space, first order in time). These types of codes use artificial viscosity to damp out numerically generated oscillations behind pressure discontinuities. Since it uses an Eulerian mesh, GUSH is diffusive. It smears both pressure and contact discontinuities over approximately six mesh cells. This behavior is essentially identical to that of other Eulerian hydrocodes using artificial viscosity. GUSH has been used extensively over several years to model airblast phenomena and has regularly been correlated to experimental data.

A second hydrocode, the NMERI RUSH (Robey's EUlerian Simple Hydrocode) program is also used. It is a second order, flux limiting, Total Variation Diminishing (TVD) algorithm. It follows the GUSH tradition of positively conserving variables. Most of the capabilities of GUSH have also been implemented in RUSH.

These hydrocodes and others are contained in a system of hydrocodes to simplify development and upkeep. This package is called MESH (Multiple Eulerian System of Hydrocodes). In addition, pre-processors called ADOBE and MARION enable quick and powerful problem setup. The addition of MPLOT and MVIEW, a general plotting package and a contour/velocity vector plotting package, respectively, provide the post-processing for the hydrocodes.

All of the calculations described in this paper were run on 486 PCs with up to 64 megabytes of RAM. On some sample problems for these hydrocodes, the 486s have been roughly estimated to run at 1/5th the speed of a CRAY-2.

Problem Setup

The calculational setup took advantage of the problem symmetry so that only a quarter section of the aircraft shelter needed to be modeled. An illustration of this initial geometry is shown in Figure 1. Initially, a uniform mesh of 6.773 cm cells was used. Ideal gas equations of state were used and the quasi-second order GUSH method was chosen. The ceiling was modeled as a smooth surface. Similar simplifications were made to the floor and door geometries. In reality, the aircraft shelter roof was made of corrugated steel, and the floor had a recess built in for the door to drop into when it opened.

The normal rule-of-thumb used in setting up calculations is that a minimum of five cells across any physical dimension is required to properly resolve the object in the calculation. In situations such as the ceiling where the resolution is not fine enough to model the details, the only correct solution is to increase resolution. This is often not feasible and a decision must be made whether to include a coarse representation of the object or ignore it altogether. The best approach is very problem

dependent.

The explosive charge of C-4 was modeled at approximately 60 cm above the floor, but only a few cells were used at this resolution and the charge was far from being the spherical charge in the experiment. The justification for using a coarse model of the explosive source is based on the source geometry and resolution being unimportant at far ranges. In reality, the coarse model of the explosive source is driven by problem run size and run time. With this resolution, the memory requirements were over 8 megabytes and the problem took a couple of days to run out to 66 msecs.

Resolution Study

Early results from similar calculations for full scale tests of aircraft shelters with small charges gave strong indications of inadequate mesh resolution for the calculation, resulting in very low peak pressure predictions. The scaled aircraft shelter tests had proportionally larger charges which should have less difficulty with resolution. Still, a serious problem with the calculational results might be possible and needed to be investigated.

To avoid substantially increasing run times and memory requirements, a fine resolution model of the explosive source was run at 1.693 cm and then mapped onto the original 6.773 cm mesh and continued. A much better approximation of a spherical charge was possible and substantial improvements in pressure waveforms resulted.

Still, the shocks were rounded and lazy, so the process was repeated for a 1.5 cm source model and a 4.5 cm model of the shelter, the smallest mesh resolution that would fit into 32 megabytes of RAM. To reduce the run time, the simulation time was reduced to under 20 msecs.

The improvement in the simulation from the rezoning and improved mesh resolution is more pronounced at gages close to the explosive charge. Thus to best illustrate the difference, station 604 placed directly above the charge was chosen to show a comparison of the three pre-test calculations in Figure 2. The initial calculation with a 6.773 cm mesh shows a clear shift in the pressure waveform due to the low resolution. This shift can be thought of as analogous to the "aliasing" of the frequency content of the waveform information similar to that commonly referred to in instrumentation theory. This theory, usually called the Nyquist theory or sampling theory requires 2 to 5 points across a period of a waveform to characterize the problem. Since the initial charge radius is a critical source of initial frequency content, it is apparent that it must be resolved to a minimum of 2 to 5 cells. This indicates that the rule-of-thumb stated earlier as requiring 5 cells minimum to adequately resolve any physical object also applies to the modeling of the energy source for this problem. Thus, the smaller the explosive source, the greater the demands on

computer memory and run times to adequately model the problem.

However, it has not been shown that the earlier argument of the explosive source model not being important if far enough away is invalid in every case. The conclusion is only that in this problem, the stations are not far enough away. As the distance from the source grows, the peak pressure error will grow smaller as the rarefaction wave drops the peak pressure and the waveform spreads out in time. The shift in time of the pressure waveform is unrecoverable, though it would become less significant as the pressure time-of-arrival grows larger at further distances. Even in this calculation, the stations at further distances show less effect from the improvement in explosive source model than the gages nearer to the charge.

The other two calculations capture the basic waveform correctly with the only difference being the peak pressure increasing as the mesh resolution increases. This is more consistent with expectations and is an indication that both these calculations have adequate resolution to properly model the explosive source. Still, the peak pressures will be truncated and will only approach the real peak pressure as the cell size approaches zero. This is the fundamental law on which finite difference numerical methods are based. At this point, the desired error in peak pressure which is wanted must be weighed against computer run times and memory requirements, which grow very quickly in 3D calculations as cell size is reduced.

Post-Test Analysis

The post-test analysis of experimental data and calculation suggested that the calculational model was missing some things that were important. The experimental data exhibited more complex waveforms than the calculational model showed. The most likely culprit would be the corrugated roof having a significant effect on the problem. This could also slow down the shock traveling along the ceiling of the shelter which would change the timing of the shock waves from the roof. The change in timing of the shock wave from the roof relative to the floor would cause the door gages in the calculation to have more of a double peak as is suggested in the experimental data.

To test the effects of adding the corrugated roof to the calculational model, another calculation was run. With only 3 cells per period of the corrugated roof, the modeling would be coarse, but it should give an indication of whether its inclusion was important. Shown in Figure 3 are four selected gages with the original smooth ceiling and the corrugated roof. From this comparison it is clear that the addition of the corrugated roof greatly improves the calculational model by adding the secondary wave peaks for the gages in the shelter ceiling in the plane of the explosive and by changing the shock wave timing on the gages in the shelter door. It is interesting to note that the gage directly

above the charge is more poorly modeled with the corrugated roof (not shown). This is however easily attributed to only two cells representing the reflecting surface where the gage is placed.

To facilitate the use of the corrugated roof in future calculational models, a program was generated to produce the input for the corrugated roof for a given mesh resolution. This was absolutely necessary to produce accurate models of the corrugations and produced well over ten thousand lines of input for many of the calculations. The program used the exact profile of the corrugations given in the construction drawings.

A weak tendency for late time-of-arrival and low impulse in the calculations as compared to the data may be explained either by increasing the explosive energy or by using a JWL equation-of-state for the explosive instead of an ideal gas equation-of-state. A test calculation using a JWL equation-of-state proved to be a negligible improvement at these resolutions. To be on the conservative side, it was decided to increase the detonation energy value for C-4 by 10% to account for some of these errors while not trying to isolate the actual source.

By now, calculations for the rest of the charge sizes needed to be run. The best model currently available was used and further analysis left till later. All the calculations were run with the 10% added energy and the addition of the corrugated roof at the maximum resolution that could fit in 64 megabytes. This resulted in a fine source resolution of 1.2 cm and a full mesh resolution of 3.6 cm. A separate calculation for the gages in the plane of the explosive was run at 1.875 cm resolution to gain higher resolution for these gages. The computational mesh used for these calculations is shown in Figure 4. The revised results for the 3.7 kg calculation compared to the data for selected gages is shown in Figure 5. The same models were then run for explosive charge sizes of 11.11 kg and 33.33 kg. The results for these calculations are shown in Figures 6 and 7.

Generally, the comparison of the results are slightly better for the larger charge sizes. The biggest limitation, however, appears to be the limited accuracy in modeling the corrugations. This is seen most dramatically for station 604 directly above the charge. Having only two cells for the reflecting surface is a major limitation in accurately modeling this station. To properly model this station would require much finer resolution than used here.

A small offset in shock wave time-of-arrival is observed on some station comparisons. The time offset is most noticeable on station 604. It is also believed that the reflected shocks that show up later in the waveforms are consistently late due to the time offset which occurs at the initial reflection. The offset may be partially attributable to the inexact modeling of the exact position of the lower surface of the corrugated roof, but not entirely. It had been hoped that the investigations into

resolution effects, etc. would show an improvement in the time modeling, but its persistence as the calculational model was otherwise improved is indicative that it is due to other factors. The suspicion turned to the GUSH numerical algorithm which sometimes shows slight time offsets such as these on problems with strong pressure gradients.

A test calculation was run using both the GUSH algorithm and the RUSH algorithm to see if the time offset was due to the algorithm rather than errors in the calculational model. Shown in Figure 8 is a comparison of the results for station 604. The RUSH results show a much better match of time-of-arrival which confirms the problem is the GUSH pseudo-second order algorithm. GUSH was selected over RUSH primarily because of its faster run time. RUSH takes approximately 3 times as long to run. With these problems already requiring over a week of run time, completely rerunning them with RUSH would require about a three week run time per calculation. It was decided that the GUSH results were acceptable and the time offset problem was mostly an academic concern now that its source was known.

Comparison of Estimated Peak

For the purposes of ranging pressure gages prior to a test event, a good estimate of the peak pressure is necessary. Two methods of obtaining peak pressure estimates were used for these experiments. The first was from the hydrocodes discussed at length in this paper. The second was from a program called INBLAST which provides pressure predictions for blasts inside structures based on ray tracing methodology and empirical formulas. After these tests, it was desired to evaluate their performance in predicting experimental peak pressures. Shown below are the comparisons for station 601.

Charge Size kg	INBLAST kPa	GUSH kPa	Experiment kPa
3.7	1191	1000	1000
11.11	2681	2482	2500
33.33	5802	5964	4200

INBLAST had some difficulty in converting C-4 to TNT though it supposedly is setup to do so. For these estimates, a hand conversion was done and the explosive weight entered as TNT. The experimental peak pressure values for the 33.33 kg tests was truncated due to non-ideal experimental effects. The overall waveform is representative of one that would have peak pressures as given in the estimates. For this station, both estimates are in good agreement with the experimental results.

The two estimating methods had varying results for other stations, depending on the station locations. The INBLAST code could not model the corrugated roof effects and the GUSH code had difficulty where mesh resolution was not adequate.

Conclusions

What at first appeared to be a relatively simple modeling task turned out to have its own complexities. As always seems to be the case in 3D modeling, resolution was very important. The effects of the corrugated roof were surprising, with important implications for the designs of similar structures. In this case the corrugated roof approximately doubled the load into the arch while reducing the peak pressures on the door. Understanding this effect could lead to better designs of arch structures to resist blasts.

The combination of experiment and calculations led to better understanding of what was happening in each one and the overall phenomenology. With only one or the other, the understanding would be very limited.

A key aspect of the calculations was the three part breakdown of the tasks into pre-test, test, and post-test. It was also important that the calculational model was continually analyzed and improved. As a result, the final calculational results were greatly improved over the initial results and a better understanding of the blast wave loading was obtained.

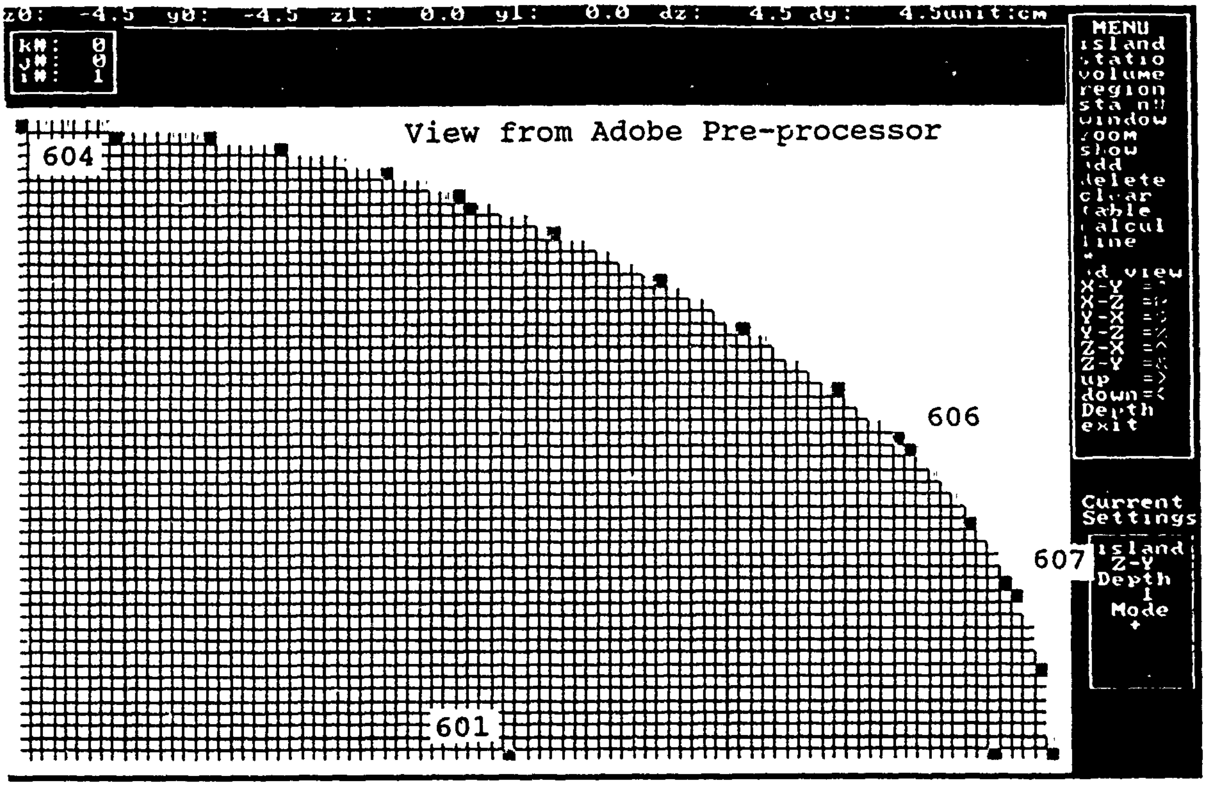


Figure 1a. Cross-Section at Explosive Plane.

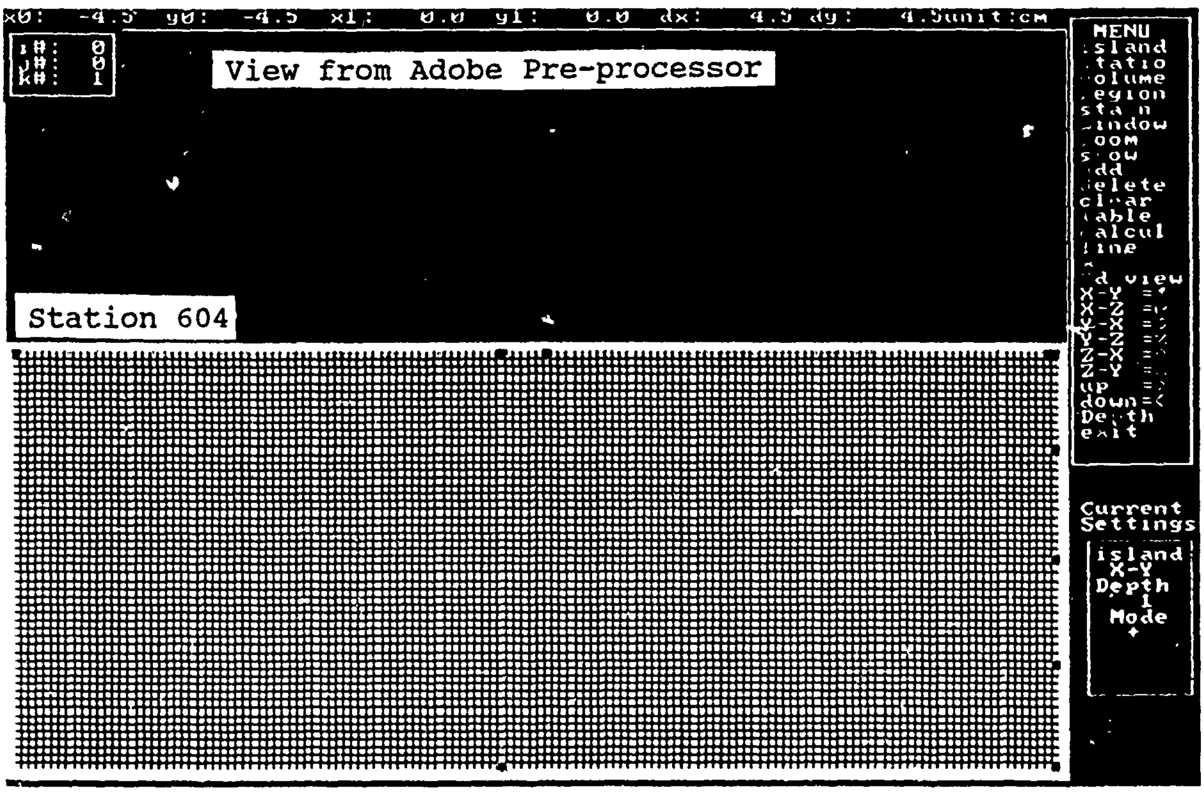


Figure 1b. Cross-Section of Model with Smooth Roof.

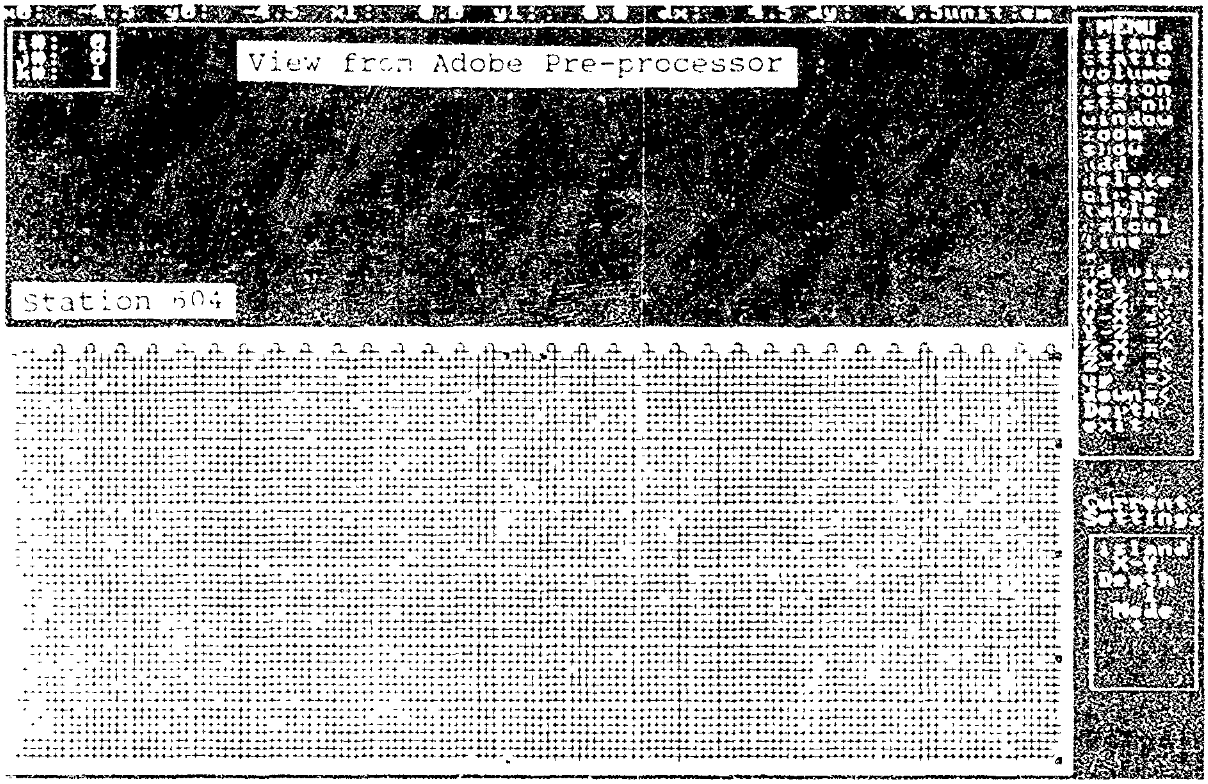
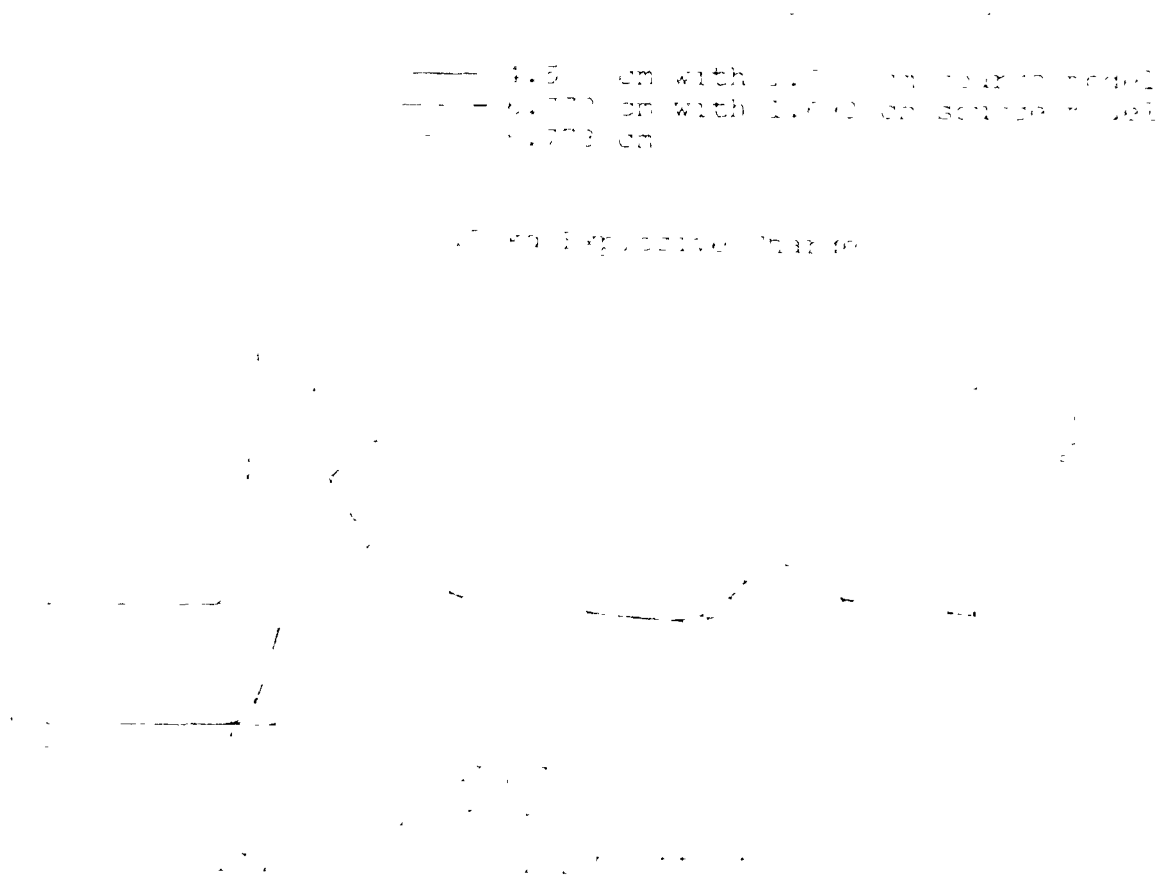


Figure 1c. Cross-Section of Model with Corrugated Roof.



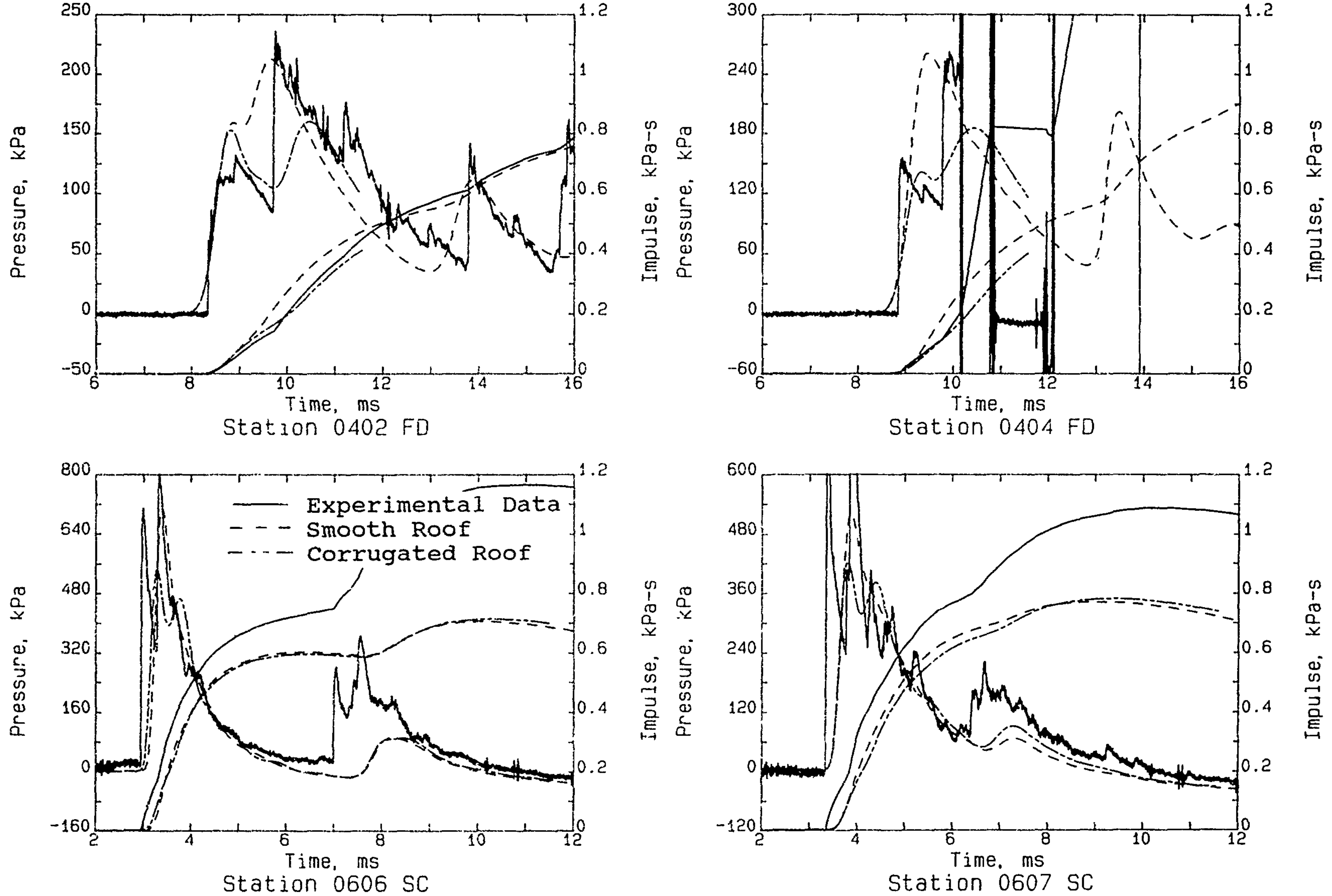


Figure 3. Effect of Corrugated Roof in Model.

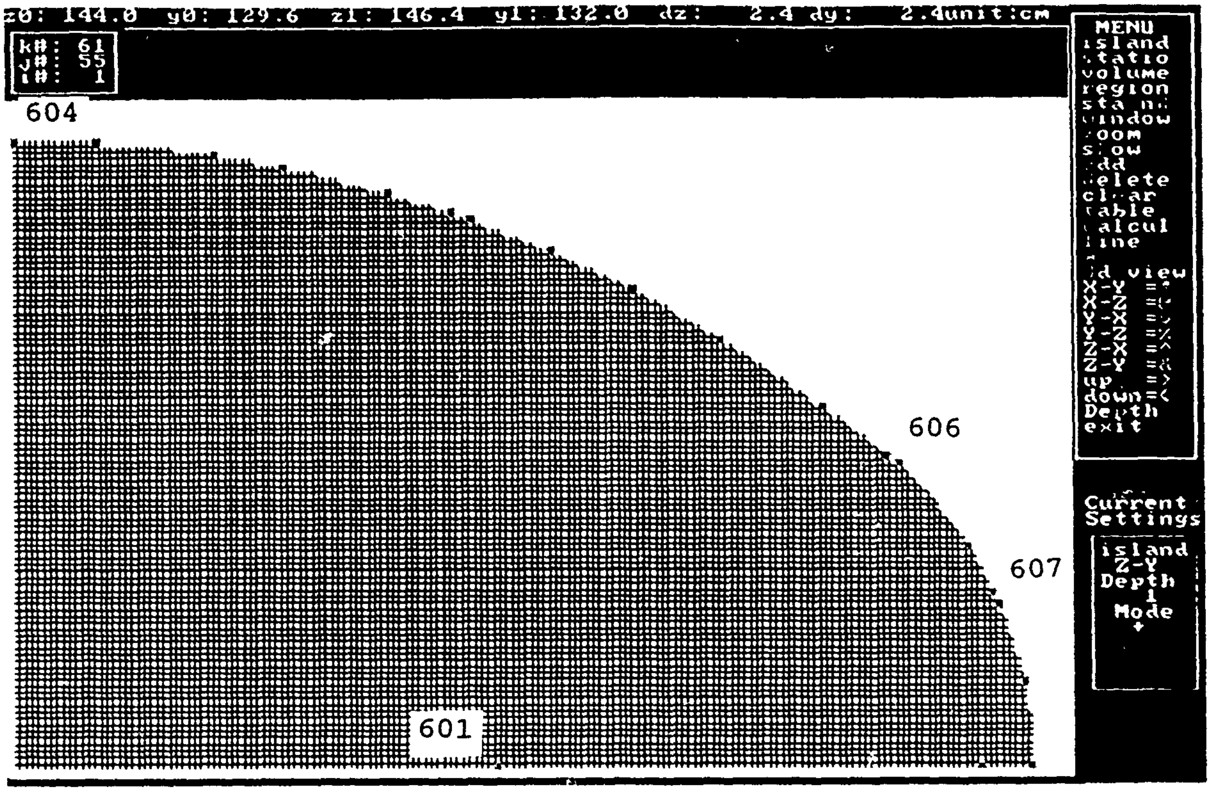


Figure 4a. Cross-Section at Explosive Plane.

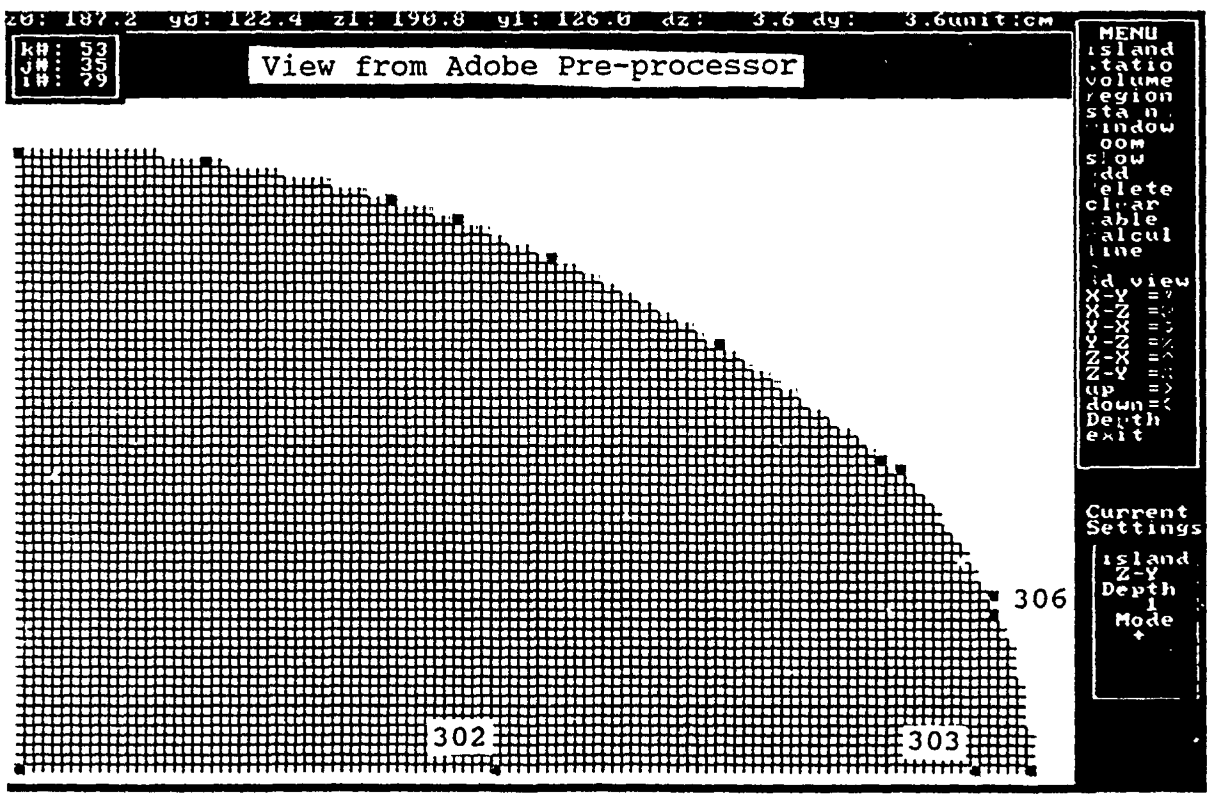


Figure 4b. Cross-Section halfway to Door.

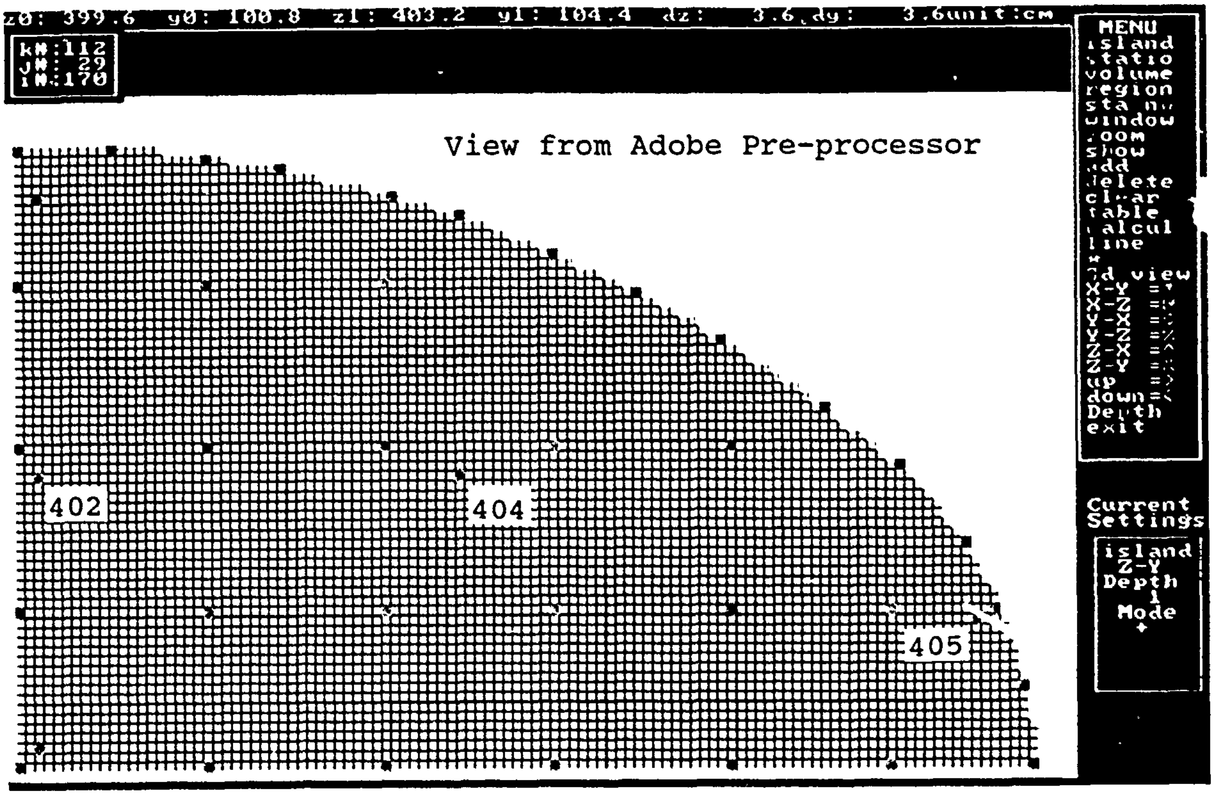


Figure 4c. Cross-Section at Shelter Door.

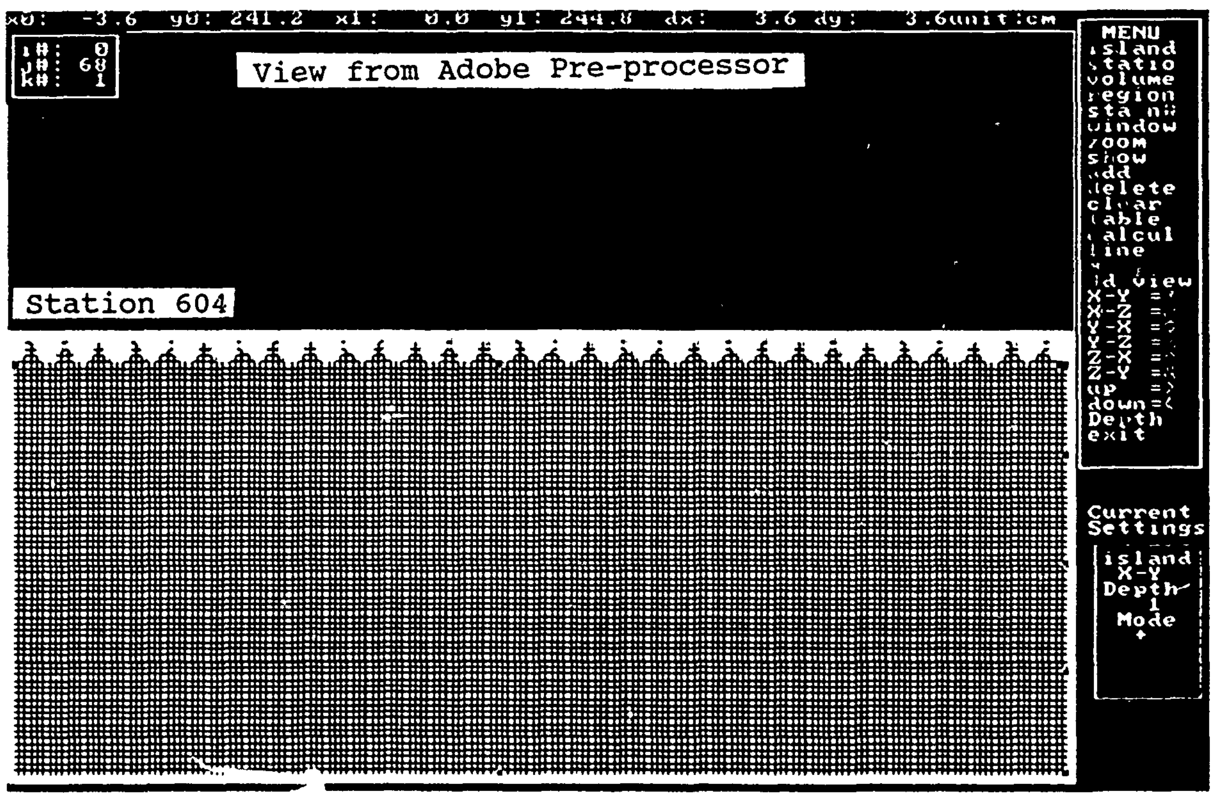


Figure 4d. Cross-Section showing Corrugated Roof.

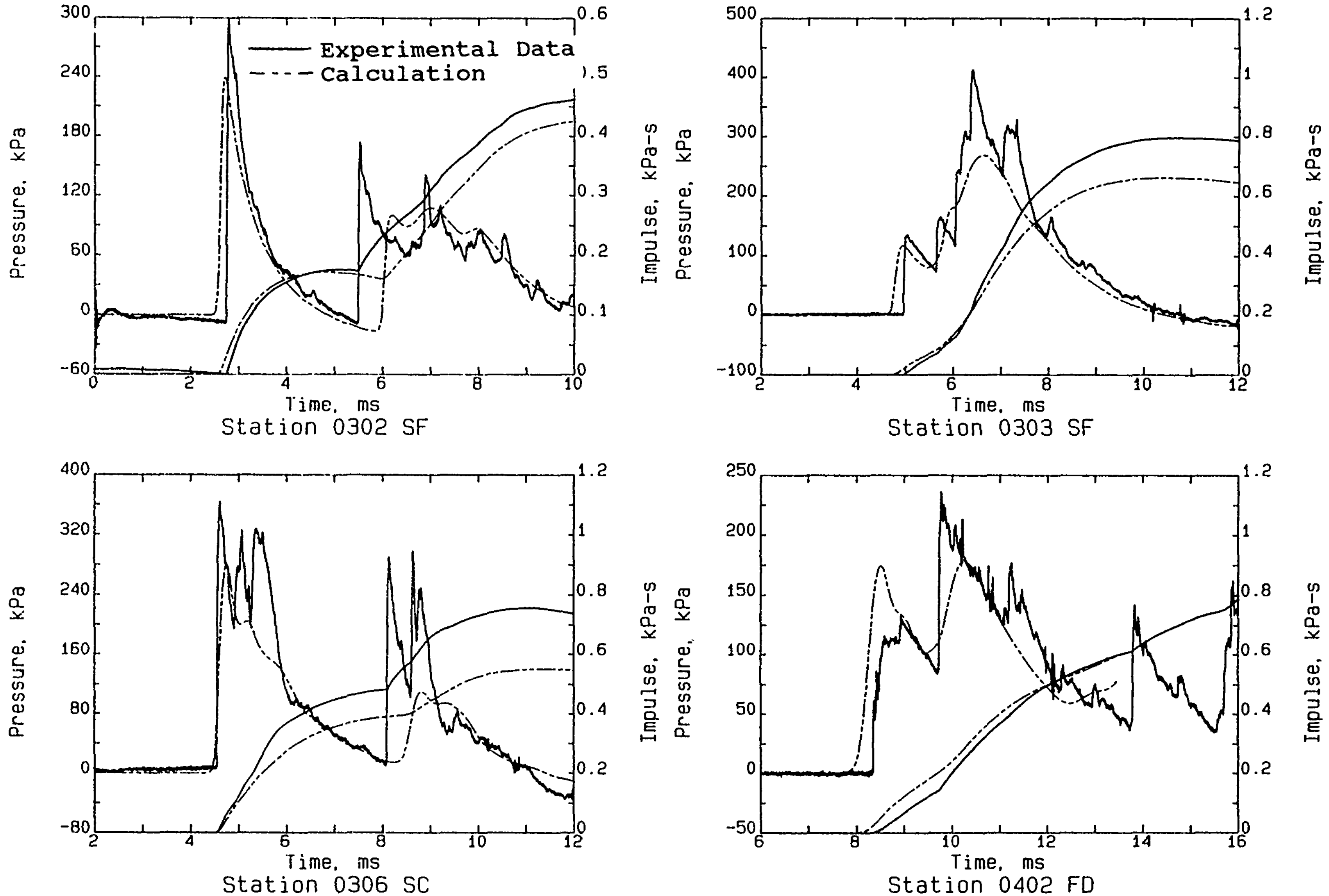


Figure 5. Results for 3.7 kg.

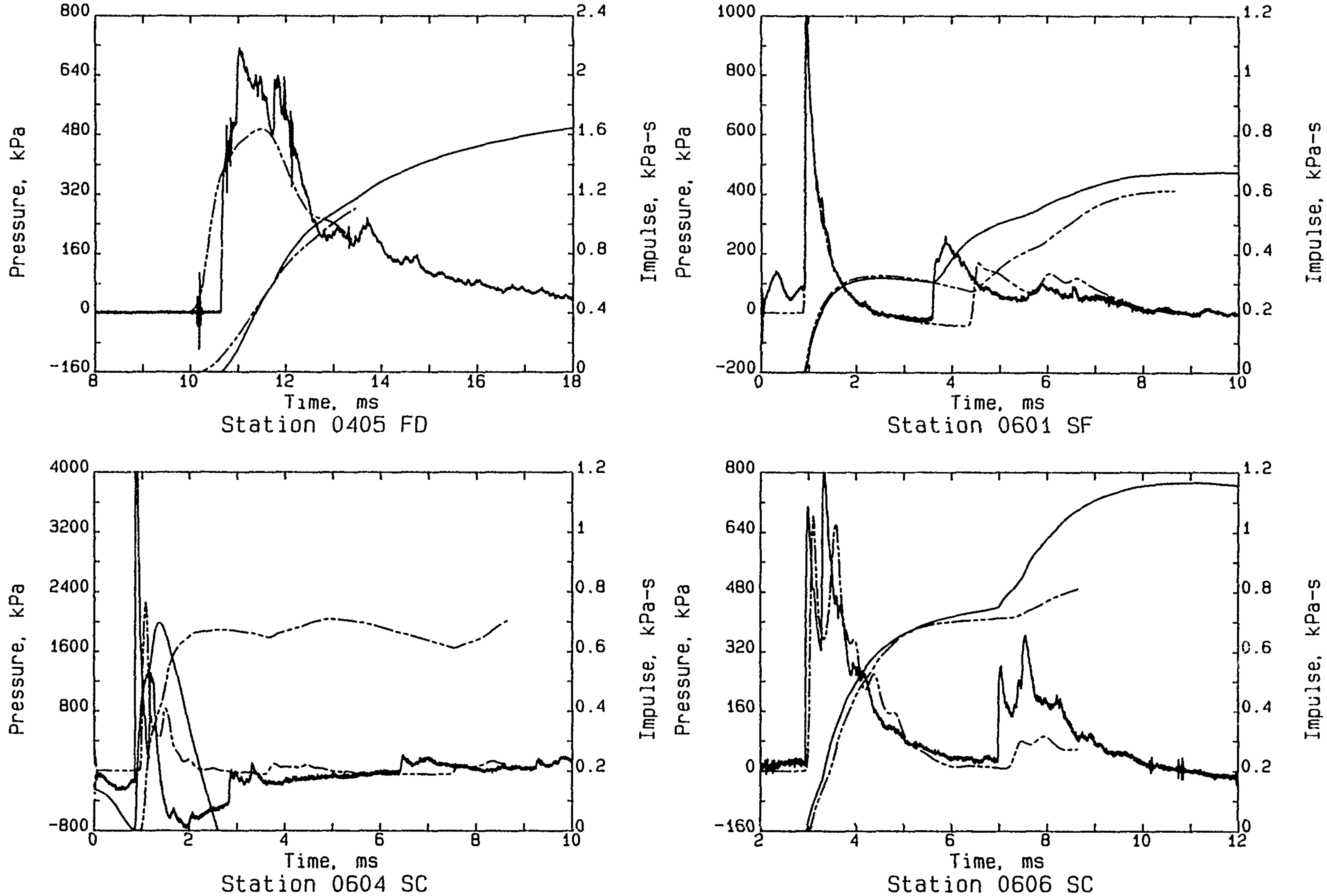


Figure 5 (cont). Results for 3.7 kg.

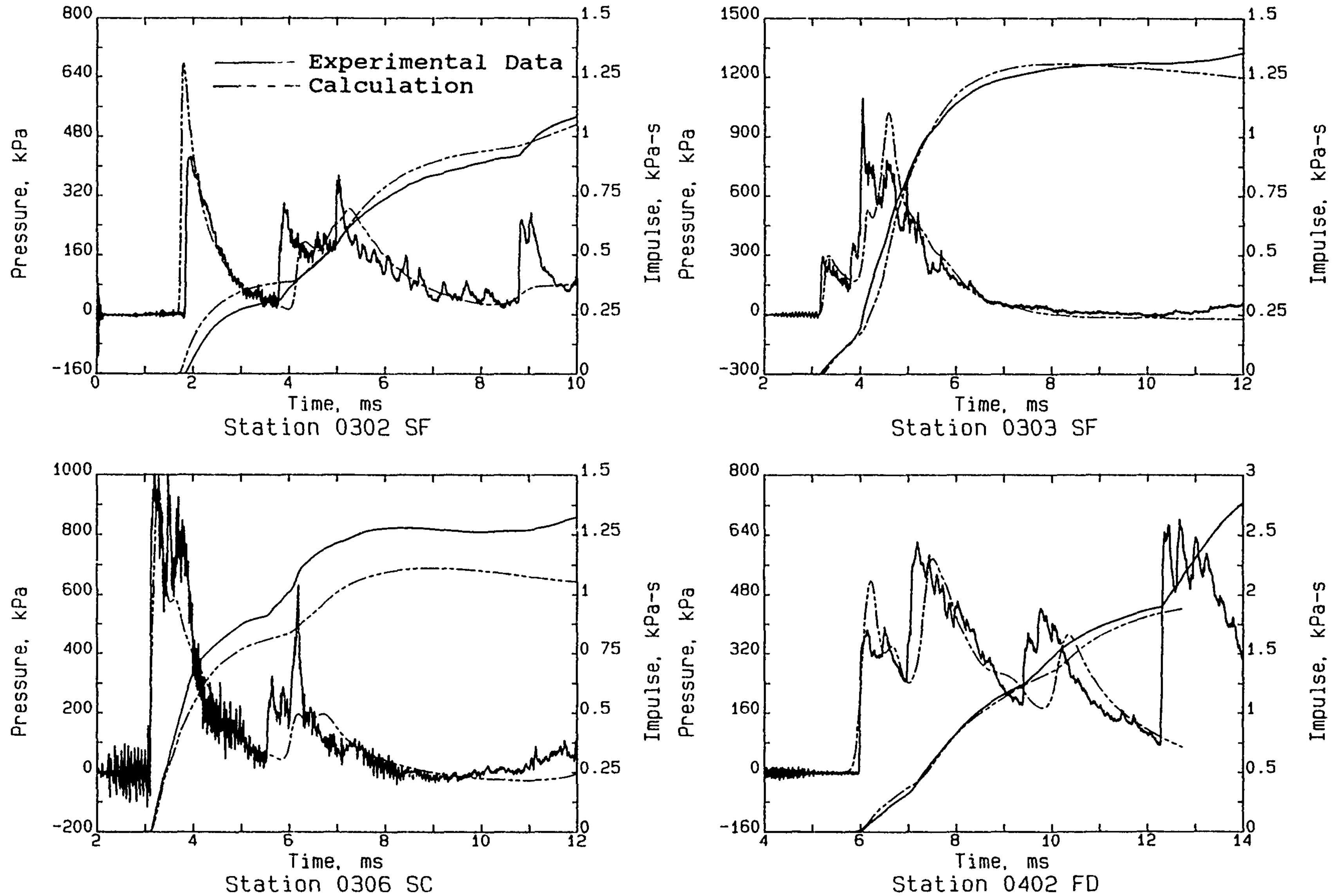


Figure 6. Results for 11.11 kg.

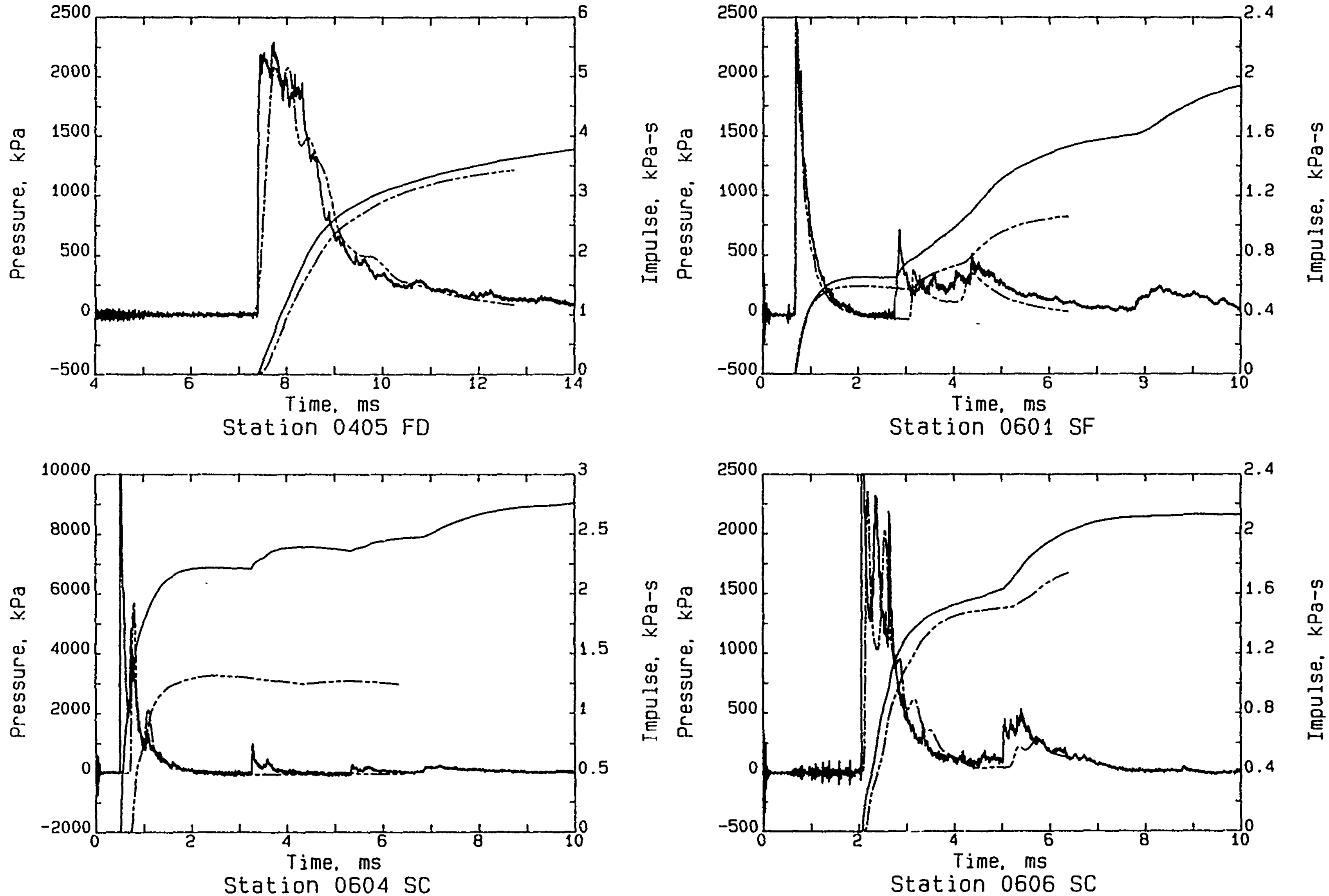


Figure 6 (cont). Results for 11.11 kg.

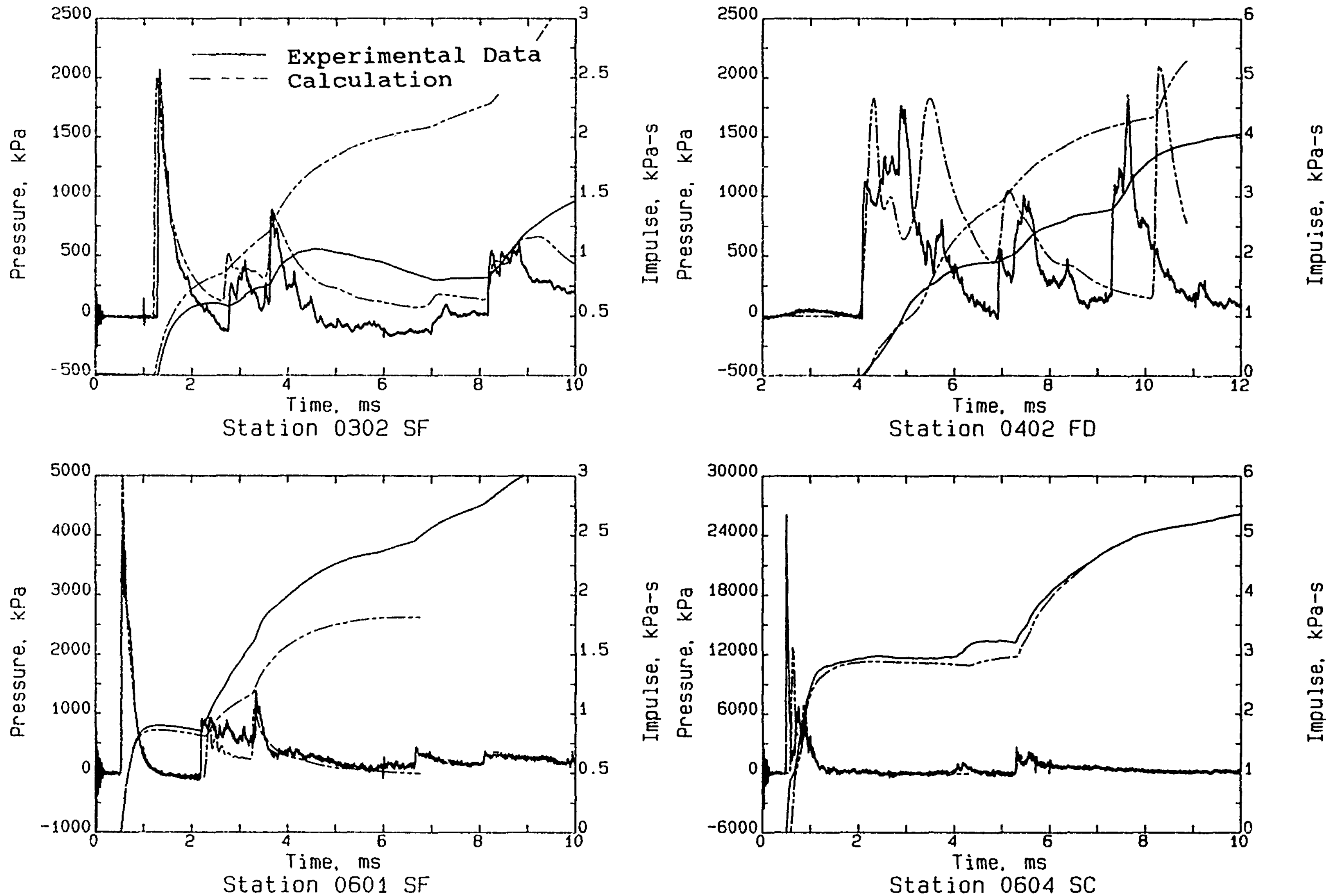


Figure 7. Results for 33.33 kg.

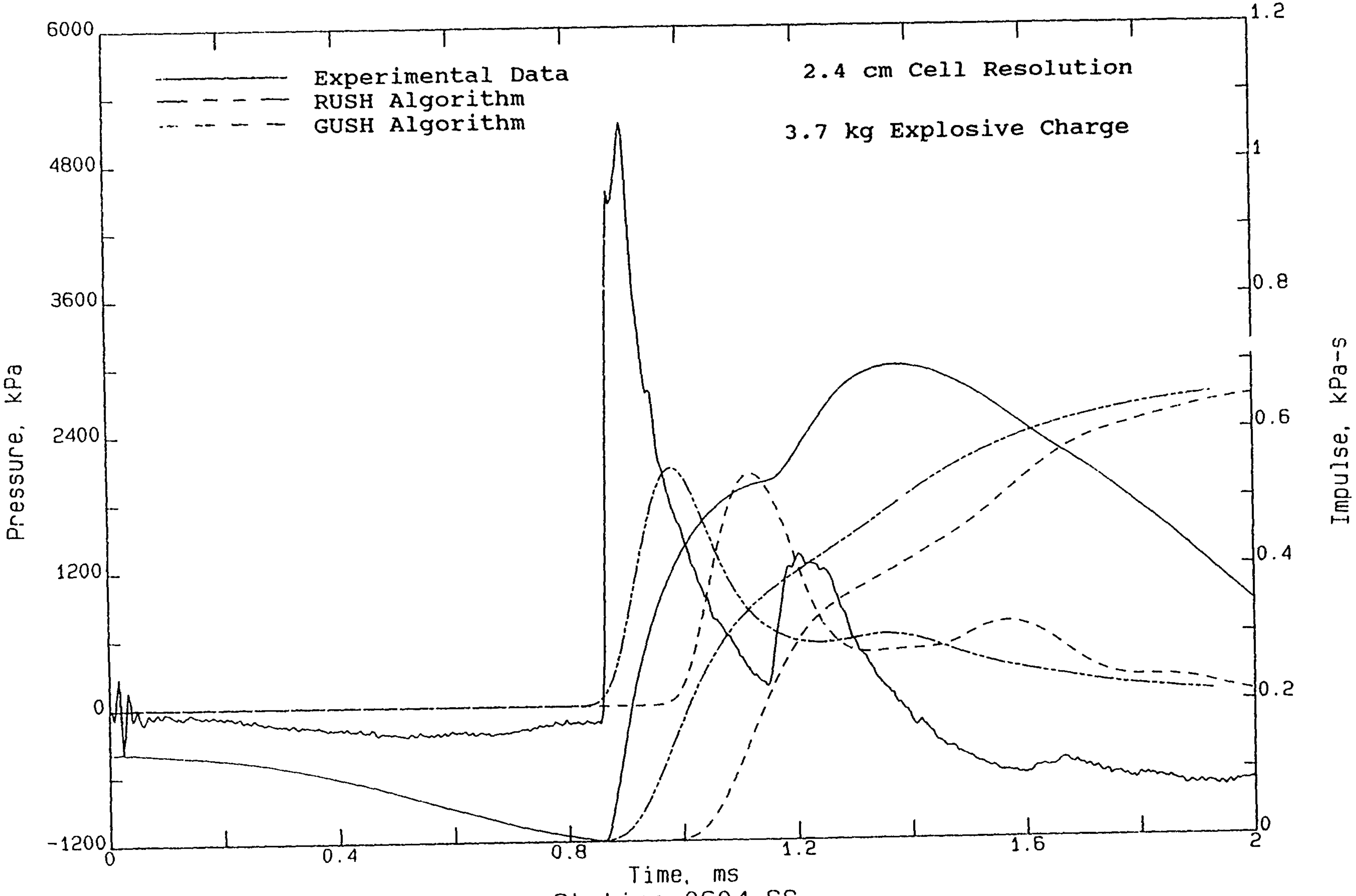


Figure 8. Comparison of RUSH and GUSH Results.

HARDENED AIRCRAFT SHELTER TEST PROGRAM

by

Michael M. Swisdak, Jr.

ABSTRACT

Operation DISTANT RUNNER produced data on the size and distribution of both airblast and debris produced by the detonation of 4500 kilograms of high explosive inside a Third Generation Hardened Aircraft Shelter. DISTANT RUNNER also produced data on the fragment/debris hazard ranges which are associated with detonations inside the shelter. After the full scale tests were completed, that event was modeled at two scales 1:10 and 1:4. These structures utilized detailed geometric modeling of both the rebar and the aggregate with which the reinforced structure was built. The concrete mixture, however, was modeled for the full-scale compressive strength. The 1:10 size model appeared to behave as if it were more like a 1:7 scale model. This appeared in the airblast, the size and distribution of the debris, and the hazard ranges produced by the debris. Because of this, testing at a larger scale was undertaken. This paper will present the results of breakup and debris throw for a quarter-scale shelter. Results obtained from all three scales will also be compared. For the structure modeled in these tests and with the decisions which were made about the details of the modeling utilized, the apparent scale factor (as determined from the breakup of the structure) differs from the design scale factor. As the scale size becomes larger (i.e., smaller models), the differences between design and apparent scale factor increases .

INTRODUCTION

During August through September 1981, Field Command, Defense Nuclear Agency (FC/DNA) conducted a five-event, high explosive test series at White Sands Missile Range, New Mexico. This test series, DISTANT RUNNER, was part of the Defense Nuclear Agency's Theatre Nuclear Forces Survivability, Security, and Safety Program. Event 4 of that series exposed one hardened aircraft shelter (HAS) to an internal pressure/fragmentation loading generated by the simultaneous detonation of 12 MK 82 General Purpose Bombs (Net Explosive Weight (NEW) 1040 kg (2292 pounds) of tritonal) inside the closed shelter. Event 5 exposed another shelter to an internal pressure/fragmentation loading generated by the simultaneous detonation of 48 MK 82 General Purpose Bombs (Net Explosive Weight (NEW) 4159 kg (9168 pounds) of tritonal) inside the closed shelter. A detailed description of the DISTANT RUNNER Program is found in References 1-5.

Because of the scope and completeness of the data generated during the DISTANT RUNNER Series, it was felt that this was an ideal opportunity to investigate/validate the use of affordable models for the breakup of reinforced concrete structures subjected to internal detonations. Five small-scale (1/10) replica models were built and tested. Event 5 of DISTANT RUNNER was the prototype for all of these 1/10-scale models. The data generated included structural breakup, debris distributions (mass and areal density), internal

and external airblast, and full-scale debris hazard range. This effort is described in References 6-7.

Analysis of the 1/10-scale results (airblast and debris size) (reported in Reference 6) indicates that the structure behaved as if it were larger than it actually was. That is, the data indicate that it behaved more like a 1/6.586 scale rather than a 1/10 scale. Reference 6 postulated several possible reasons for this difference in breakup. These included: (1) concrete strength, (2) use of welded wire mesh instead of rebars, and (3) scaling of the surface energy of the concrete.

Because of the questions that grew out of the analysis of the 1/10-scale data, it was proposed that a further series of experiments at a larger scale (approaching 1/3 to 1/4) be undertaken. This program was to include developmental "slab" tests at various scales before a full model (at a scale to be determined) was built. Because of funding constraints, it was decided to jump directly to the larger model test, omitting the intermediate "slab" tests which were to be used to better describe the concrete breakup, shape, and mass distributions as a function of scale. After investigation, it was decided that the most economical scale (from the standpoint of the availability of materials) was 1/4-scale. In 1990, one 1/4-scale model aircraft shelter was constructed at the New Mexico Institute of Mining Technology (NMIMT), Socorro, New Mexico. Twenty-nine days after the final concrete pour (exhaust port), the model was tested. Reference 8 describes the NMIMT effort in model construction and data collection.

MODEL PHILOSOPHY

The 1/10-scale trials were designed to model both the external shots as well as Event 5 of DISTANT RUNNER. In addition, a mass model of an aircraft was included inside each shelter. Each MK 82 bomb and its location was also modeled. Internal and external airblast were measured on each shot. After this test series was completed, it was the consensus that the pre-conditioning shots (external airblast events) did not contribute to the strength (or weakness) of the model and could be eliminated from any further testing effort. Moreover, the mass model of the airplane did not seem to contribute to shelter response or to the external debris (only small amounts of material attributable to the airplane model was located outside the shelter). As a result, for the 1/4-scale test, no airplane model was included and airblast was not recorded.

1/4-SCALE MODEL DETAILS

The total NEW on DISTANT RUNNER Event 5 was 9,168 pounds--contained in 48 Tritonal-loaded MK 82 bombs. When the NEW is calculated for 1/4-scale, it is 143.25 pounds of tritonal. It was decided to substitute Composition C-4 for the tritonal. When the TNT equivalences are taken into account, approximately 130-140 pounds of C-4 are required, depending upon the TNT equivalence selected. Each bomb case was simulated by iron pipe with nominal outer diameter 2.625", inner diameter 2.386", and length 13.5 inches. A 0.375" end cap was welded on one end. The total explosive weight (including C-4 explosive and the C3 DETASHEET used to initiate it) was 137.08 pounds. All bomblets were initiated simultaneously, using identical lengths of NONEL and detonating cord. Figures 1 and 2 show the locations of each bomblet stack.

The shelter was constructed using one-quarter scale reinforcing bar which was welded into mats of the appropriate diametei (0.207" and 0.120") and spacing. The concrete mix used for the structure was scaled from the DISTANT RUNNER mix, with adjustments made for availability of materials and producibility. Test specimens of all concrete mixes were taken and compressive strengths as a function of cure time were determined. All were near or exceeded 4000 psi at the time of the test. The double-corrugated liner material was not readily available. A single manufacturer was located and the material was manufactured to the appropriate dimensions.

The blast deflector design was scaled up from the 1/10-scale models, rather than scaled down from the full scale. At the time of the 1/10-scale tests, it was decided that this simplification would not affect the quality of the results and would greatly simplify construction, thereby reducing costs.

The floor was joined to the walls of the structure in the same manner as was done on the 1/10-scale models. This has proven to be a point of concern. After discussions with the Department of Defense Explosives Safety Board (DDESB), it was decided that the 1/4-scale test should model the 1/10 scale tests, rather than the full scale event. Several different schemes have been used in prototype structures to join the walls of the shelter to the floor slab. One of these where the walls are lightly tied to the floor was modeled on both the 1/10-scale and the 1/4-scale tests.

RESULTS AND OBSERVATIONS

The test was conducted on September 5, 1990. A general impression of the observers present was that the model appeared to break-up into larger pieces than had been expected. In fact, what appeared to be the entire side wall of the structure could be seen flying through the air. It must be pointed out, however, that this same phenomena was observed on DISTANT RUNNER Event 4. On that event, the side wall appeared to fly, wing-like, over the fiberboard fragment recovery bundles, landing in front of one of the high speed cameras.

On DISTANT RUNNER, the massive blast deflector remained relatively intact. For the modeling effort, the construction details were simplified. These simplifications did not seem to alter the results. The blast deflector remained a monolithic structure and travelled a short distance.

Based on the final location of the pieces of the front door and an examination of the area surrounding their impact point, it can be concluded that the front door came off almost intact (two major pieces) and seemed to break up upon impact with the ground. It hit and stopped within the 5° recovery zone located out the front. (Note: the pieces were recovered within the 5° recovery sector.) If the door had been broken into more than a few large pieces before it was expelled from the shelter, the impact points would have shown a much greater dispersion.

After the event, the material located within the 5° recovery sectors was recovered, weighed, measured, and cataloged. In addition, over 160 pieces of large debris, located outside the 5° sectors, were also surveyed, recovered, and analyzed.

Figure 3 is a survey map of the large debris pieces which were located separately from the material in the 5° sectors. Over 160 large pieces of debris are included in this category. The front of the shelter is located at 0° (North), the recovery side of the shelter at 90° (East), and the rear at 180° (South). The 270° side faced a steeply up-sloping hill; thus, very little recovery effort was expended in this direction. If Figure 3 is compared with similar maps generated for both the 1/10-scale (such as Figure 4-1 of Reference 6) and full scale events (Figure 14 of Reference 3), no outstanding differences are apparent.

Prior to the event, displacement cubes were placed on and around the outside of the structure. The reason for installing these cubes was twofold: (1) to act as debris of known size to be tracked photographically, and (2) from their final locations and known initial starting points, to be able to back-calculate their launch velocity and angle.

There were two types of cubes used: (1) 2-inch aluminum cubes, weighing 0.75 pounds each (a total of ten were used) and (2) 6-inch wooden cubes, weighing approximately 4.1 pounds each (a total of five were used). Figure 4 is a sketch of the locations of each of the cubes.

Out of the fifteen cubes emplaced prior to the test, thirteen were recovered afterward. One of the wooden cubes had broken into two pieces, but both pieces were recovered. Two of the aluminum cubes were never located. Table 1 gives the final locations of each of the cubes. None of the cubes could be seen in any of the high speed photographic coverage. Using the information presented in Table 1 as well as the initial locations of the cubes, a series of trajectory calculations was performed to bracket the initial launch conditions required for the cubes to land where they were found. The computer program TRAJ[9] was used for these calculations.

The sloping terrain present at the test site was included in the trajectory calculations. In addition, the ricochet option was enabled, with the soil being described as dry sand (Soil Constant = 2.00). For those cubes in direct contact with the side of the shelter, it was assumed that the launch angle was within $\pm$ 15 to 20° of the normal from the center of the shelter to the cube location. The results are shown in Table 2. Relatively low velocities were obtained, with consistent results being obtained from both types of cubes. It must be remembered that there is no unique combination of launch velocity and angle for a given final location--rather a range of angles and velocities.

With the exception of the cubes located on the very top of the structure, the velocities were all less than 200 ft/s. From the top of the structure, the velocities could be as high as 600 ft/s. However, based on information presented in Reference 6, an upper limit of 400 ft/s would seem to be more realistic.

Before any appreciable breakup or movement could be observed on the high speed photography, the entire scene is engulfed in flame and smoke. At very late times, approximately 100 milliseconds or more after detonation, the large debris pieces emerge from the cloud/dust and can be tracked. The velocities obtained are quite consistent with those obtained on the 1/10-scale model tests. It should be remembered that no velocity data was obtained on Event 5 of DISTANT RUNNER. On DISTANT RUNNER, the fireball obscured all useable data.

ANALYSIS

Over 35,000 separate pieces of debris are reported and cataloged. However, only those pieces weighing over 30 grains (1.9 grams) were considered in the following analyses. Calculations performed for the analysis of both the full-scale DISTANT RUNNER and the tenth-scale models showed that full-scale concrete debris must weigh at least 0.3 pounds to be hazardous. A 1.9 gram debris piece from a quarter scale model would correspond to 121.6 grams (0.26 pounds) full scale. Even after the lighter debris pieces were eliminated, there were approximately 19,000 debris pieces to be considered.

Samples of the concrete debris collected in the 5° recovery areas were evaluated as to shape factor. The shape factor relates the debris weight with a length dimension according the relationship:

$$M = B*\rho_c*L^3 \qquad (1)$$

where

M	=	Debris mass or weight
B	=	Shape Factor
ρ_c	=	concrete density, nominally 150 lb/ft^3
L	=	(debris length x debris width x debris thickness)$^{1/3}$

The shape factor represents the fraction of the volume of the box determined by the debris, when that box is filled by the debris of mass M with density ρ_c. Note that the dimensions (length, width, thickness) specify a box size within which the debris item can just fit. This is shown schematically in Figure 5.

Samples were selected from all three directions and statistically analyzed for shape factor and the effects of sieve size. For each direction, the average shape factor was 0.38. There was no apparent size effect. When the data are combined, an estimate of the shape factor for the 1/4-scale model can be established. This was 0.38 $\pm$ 0.06, based on 4,478 samples. The average value obtained for DISTANT RUNNER was 0.44 $\pm$ 0.03 (based on 5,837 samples); that for the tenth-scale models was 0.47 $\pm$ 0.03 (based on a total of over 22,000 pieces for the five models).

The differences between the tenth-scale and the full-scale are statistically significant (at the 95% confidence level), as was pointed out in Reference 6. A similar, statistically significant, difference between the quarter-scale and the full scale results was also found. The effect of these differences is to contribute to the over-estimation of debris ranges based on the tenth- and quarter-scale results.

Porzel, in his development of the Technology Base for the Naval Explosives Safety Improvement Program[10], postulated the following number distribution for the breakup of materials:

$$N(>L) = N_0 e^{-(L/LBAR)} \qquad (2)$$

where

N(>L)	=	Number of debris pieces with length greater than L
N_0	=	Total number of debris pieces (determined by fit)
L	=	Debris Length
LBAR	=	Characteristic debris length, in same units as L (determined by fit)

This distribution has been applied to the fragmentation or breakup of a wide variety of items including primary fragments from bomb cases following a detonation, pieces of a broken dinnerware plate, and sizes/numbers of pieces of naturally occurring coal. In Reference 3, this distribution was applied to the data generated on Events 4 and 5 of DISTANT RUNNER It was observed in this case that there appeared to be at least two characteristic sizes of the debris rather than one and the technique was not pursued further.

Figure 6 illustrates a typical example and the application of equation 2 to the data generated during this test. At least two break points are identified. Their location is chosen to maximize the correlation coefficient obtained fitting equation 2 to a portion of the data. One curve is fitted to the data below Break 1; a second equation is fitted to the data lying between the first and second break. The values of LBAR obtained in each portion as well as the location of the break points themselves can then be compared to determine appropriate values of scale factors. For example, let us assume (arbitrarily) that an LBAR of 1.65 inches was obtained for the full scale results and an LBAR of 0.50 inches for the nominal quarter scale. Then the apparent scale factor is simply 1.65/0.50 or 3.30. Similarly, let us assume that the first break point occurred at 7.5 inches full scale and 2.5 inches, quarter scale. In this instance, the apparent scale factor is 7.5/2.5 or 3.0. The location of the second break point could, theoretically, be used to determine an apparent scale factor. However, because of the smaller amount of data available in this portion of the distribution, the results may not be as accurate.

Figures 6, 7 and 8 present the debris-number distributions, based on debris length, obtained for the three scale sizes: full scale, tenth scale and quarter scale. The full-scale distribution, Figure 7, differs slightly from the one appearing in Reference 3. Additional data were added to the distribution, small errors were corrected, and the results recalculated for this report. Table 3 presents a summary of the apparent model scale factors based upon this method. For the tenth-scale model, the apparent scale factor varied between 7.405 and 9.5, with an average of 8.660. The quarter scale apparent scale factor varied between 3.00 and 4.01, with an average of 3.418.

HAZARD RANGES

The debris ranges obtained from the model results must be scaled to full scale before hazard ranges can be computed. Unfortunately, the scaling of debris ranges is not straightforward, since gravity was not scaled in the model experiments. A scaling algorithm was developed and reported in Reference 6. Essentially, given the location of each piece of debris in the model scale, estimates are made of the launch conditions required to place it at that location. The debris piece is then scaled to full scale, the previously-calculated launch conditions applied, and the "full-scale" debris trajectory is calculated. This is repeated for

each debris piece. As indicated above, the algorithm is detailed in Reference 6. As a check on the algorithm, the procedure was applied to the full scale DISTANT RUNNER results. If the procedure is working appropriately, the same debris locations as the input conditions should be returned when the algorithm is applied. This was, indeed, the case.

Certain assumptions and information are required before the algorithm can be applied. These include the densities and shape factors of the debris. In addition, a debris cut-off velocity must be specified. When a piece of debris impacts the ground and breaks up into smaller pieces, one result is an unrealistic estimate for the initial velocity of the intact piece. When the calculated initial debris velocity exceeds this specified value, that particular piece of debris is not considered further. A value of 400 ft/s has been utilized in all these debris analyses. This value is consistent with both the photographically-determined and the displacement cube-inferred velocities previously reported.

Since the debris analyses were performed and reported in References 3 to 7, additional work[11,12] has been performed on the standardization of such analyses. One important difference is the calculation of a pseudo-trajectory normal (PTN) hazardous fragment density. These new techniques have been applied to the original DISTANT RUNNER Event 5 data as well as to the data from the five tenth-scale models. The results are shown in Table 4. The ranges were only slightly different using both the old and the newer, preferred technique.. The quarter-scale results are very similar to the full scale DISTANT RUNNER results out the side and the rear, but are significantly longer out the front. Out the front, the quarter-scale results more closely resemble the tenth-scale results.

On both the tenth-scale and quarter-scale models, the front door assembly hit within the recovery sector, bounced, and broke up. On the full scale event, the door landed outside the 5° recovery sector. This would help to explain why the hazard range in the direction to the front of all of the models was significantly greater than the DISTANT RUNNER range.

SUMMARY

Three distinct sizes of reinforced concrete structures have now been constructed and tested to destruction: (1) DISTANT RUNNER at full scale, (2) a series of five tenth-scale models, and (3) one quarter-scale model. In the most general terms, all three behaved in a similar manner.

One objective of the model testing is to determine if the hazard ranges can be inferred from the model results. DISTANT RUNNER showed that the explosives safety quantity-distance (ESQD) range for these third-generation hardened aircraft shelters was controlled by the debris/fragmentation rather than airblast. The series of tenth-scale model tests showed that the full-scale airblast results were, indeed, adequately predictable from these model data. Because of this and because the airblast did not drive the ESQD range, airblast was not measured on the quarter scale test.

The tenth-scale models overpredicted the debris hazard range in all three directions. The quarter-scale model agreed with the full-scale results off the side, slightly underpredicted them off the rear and overpredicted them out the front. One reason both the tenth- and quarter-scale models overpredicted the range out the front is because of the

behavior of the front door. At full scale, the doors seemed to hold together and landed outside the recovery sectors, not influencing the debris density for the front recovery sector. On both model scales, the doors landed within the recovery sectors.

At the 95% confidence level, the shape of the recovered debris (as measured by the debris shape factor) for both the tenth- and quarter-scale results, was statistically different from the full-scale results.

The apparent scale factor, i.e., the scale factor inferred from experimental data, was less than the design scale factor for both model scales. At tenth-scale, the average apparent scale factor (as determined by the length distribution) was 8.66 rather than 10. At quarter-scale, the factor was 3.42.

Another objective of this program was to examine the relationship between the "design-scale" of a model and its "apparent-scale", as determined from its breakup behavior. Figure 9 presents this relationship as determined for the reinforced concrete structures tested during this program. A caveat must be applied here. Only this one type of structure has been considered. The relationship shown in Figure 10 may not apply to another type of structure or to a similar structure if significant changes are made in the way in which the structure is modeled.

These series of tests have indicated that the breakup behavior of reinforced concrete structures can be inferred from model results. The gross breakup pattern is similar. The shape factors are nearly identical. The hazard ranges mirror the full scale numbers.

REFERENCES

1. LTC Flory, R. A., "DISTANT RUNNER," Minutes of the 19th Explosives Safety Seminar, DoD Explosives Safety Board, September 1980.

2. LTC Flory, R. A., "DISTANT RUNNER Results," Minutes of the 20th Explosives Safety Seminar, DoD Explosives Safety Board, August 1982.

3. Ward, J. M., "DISTANT RUNNER-Debris Recovery and Analysis Program for Events 4 and 5," Minutes of the 20th Explosives Safety Seminar, DoD Explosives Safety Board, August 1982.

4. Ward, J. M., "Debris Recovery And Analysis Program For DISTANT RUNNER Events 4, and 5,"Proceedings of the DISTANT RUNNER SYMPOSIUM, 27-28 April 1982, 2 September 1982.

5. Ward, J. M., Debris Hazards From Internal Explosions in Hardened Aircraft Shelters, NSWC TR 86-114, 16 April. 1986.

6. Ward, J. M., et. al., Modeling of Debris and Airblast Effects From Explosions Inside Scaled Hardened Aircraft Shelters, NSWC TR 85-470, 3 May 1986.

7. Swisdak, M. M., Aircraft Shelter Model Test (ASMT) Follow-up Analyses, NSWC TR 86-472, 30 September 1986.

8. Harvey, K. L., One-Quarter Scale Third Generation Hardened Aircraft Shelter Test Results, NMT/TERA No. T-91-1834-U, 19 June 1991.

9. Montanaro, Paul, "TRAJ--A Two Dimensional Trajectory Program For Personal Computers," Minutes of the 24th Explosives Safety Seminar, DoD Explosives Safety Board, August 1990.

10. Porzel, F. B., "Technology Base of the Navy Explosives Safety Improvement Program," Minutes of the 19th Explosives Safety Seminar, DoD Explosives Safety Board, September 1980.

11. Swisdak, M. M., "Analysis of the Debris Produced By A Processing Building Accident," Minutes of the 23rd Explosives Safety Seminar, DoD Explosives Safety Board, August 1988.

12. Swisdak, M. M., "Procedures For the Analysis Of The Debris Produced By Explosion Events," Minutes of the 24th Explosives Safety Seminar, DoD Explosives Safety Board, August 1990.

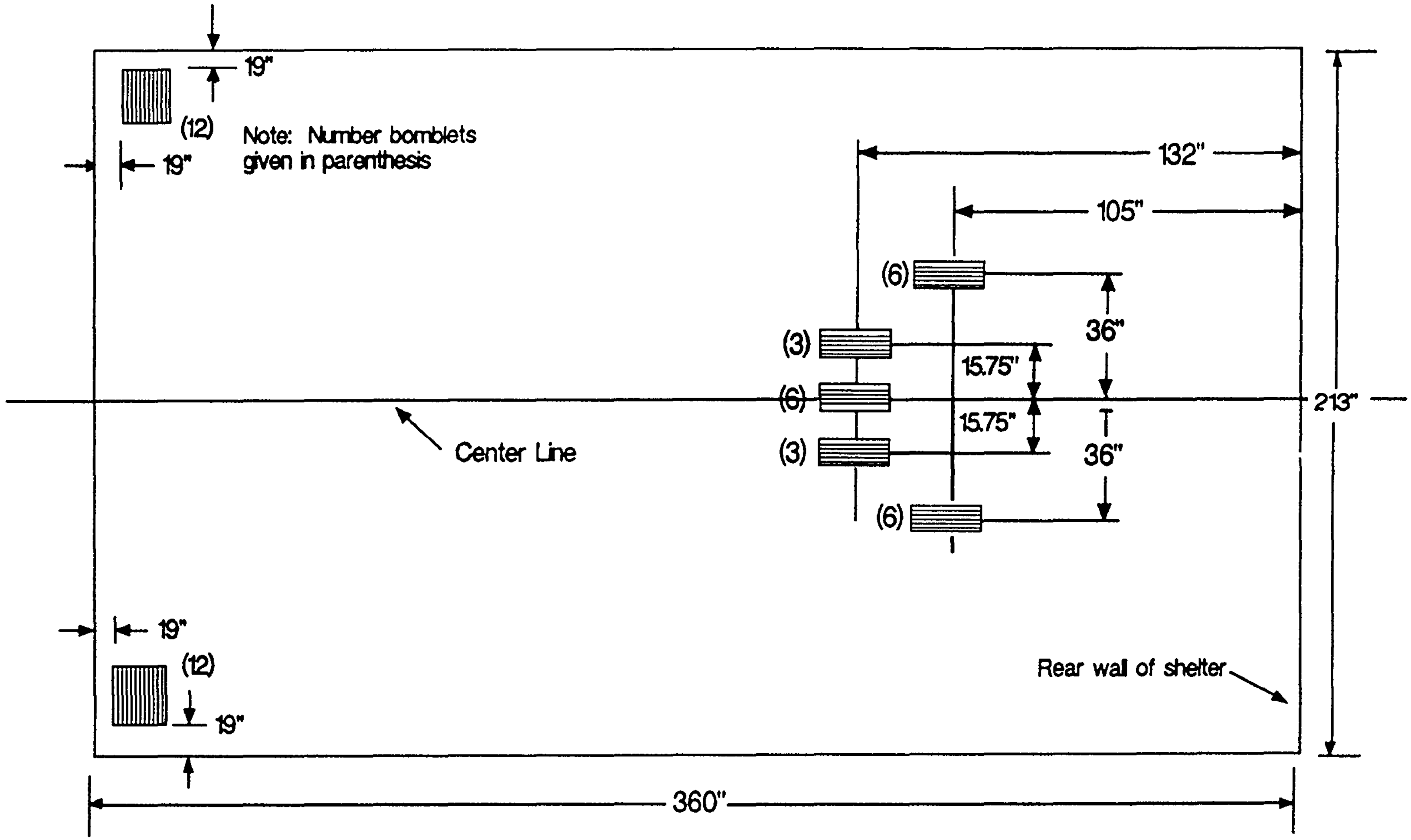


FIGURE 1. PLAN VIEW OF QUARTER SCALE SHELTER SHOWING BOMBLET LOCATIONS

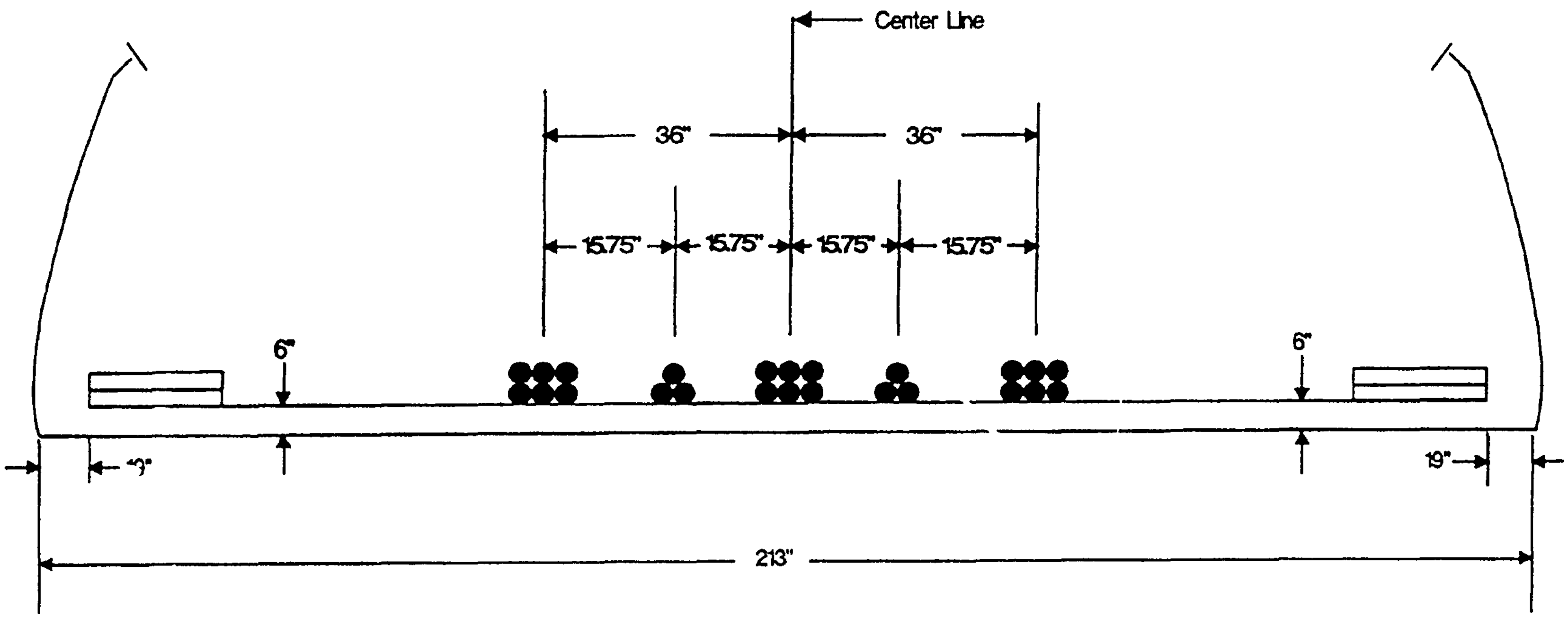
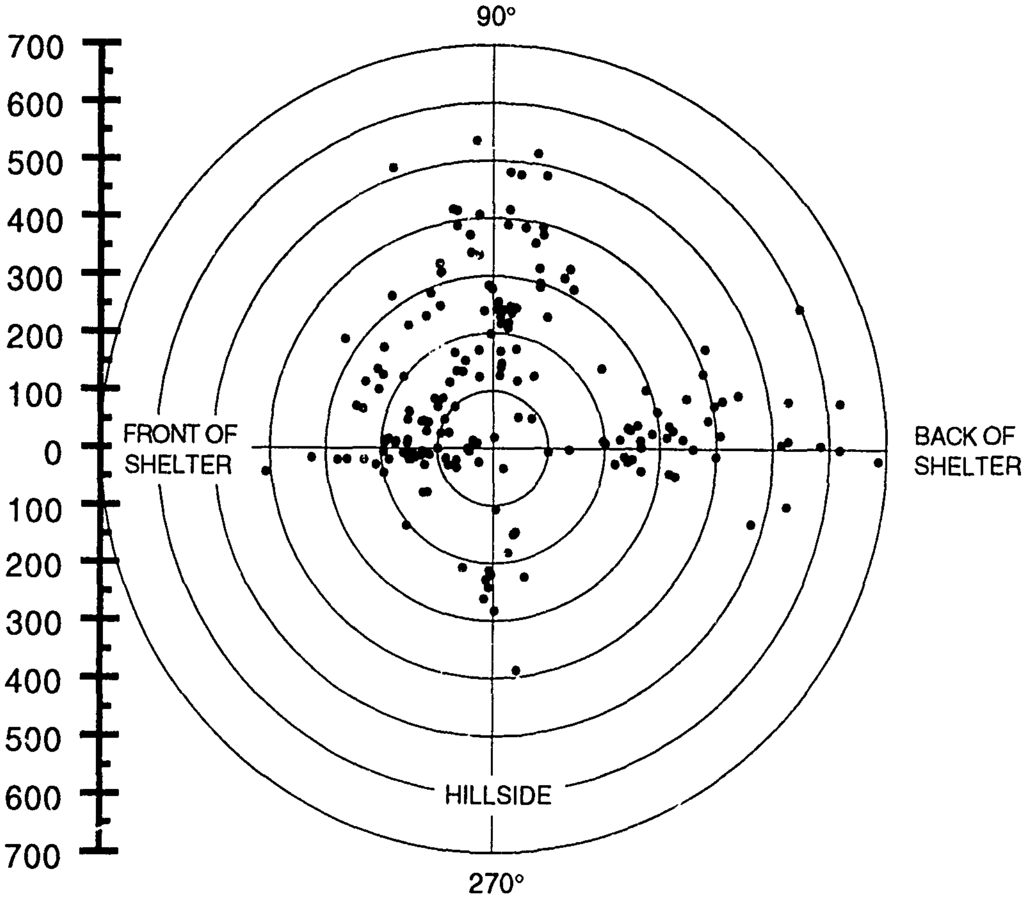


FIGURE 2. FRONT VIEW OF QUARTER-SCALE MODEL SHOWING BOMBLET LOCATIONS

FIGURE 3. SURVEY MAP OF LARGE DEBRIS



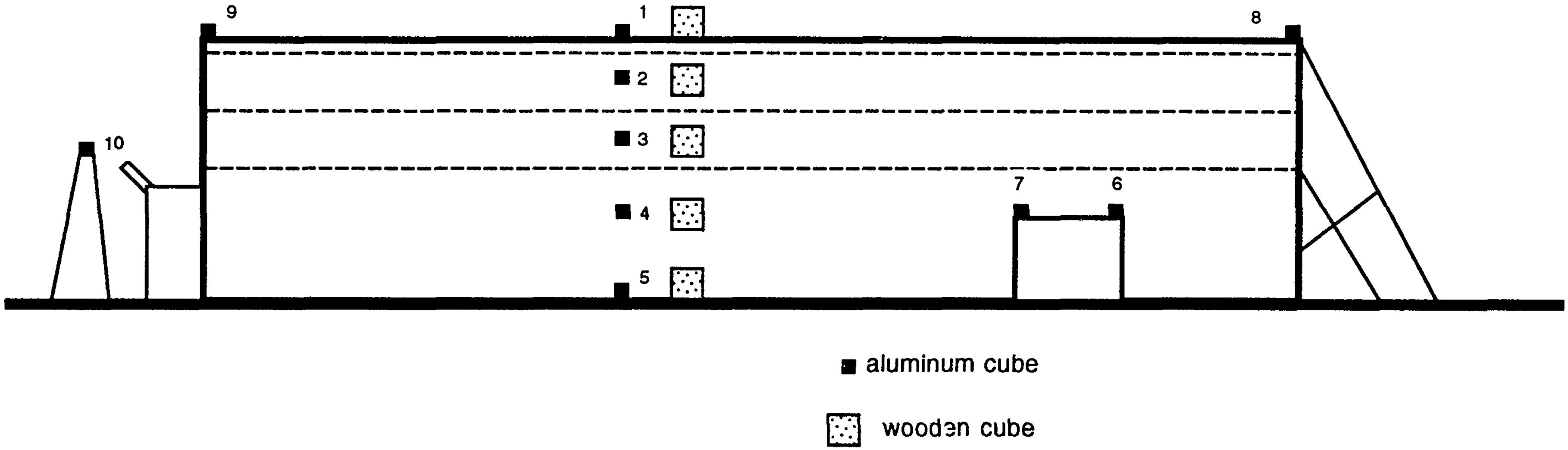


FIGURE 4. 1/4-SCALE SHELTER: DISPLACEMENT CUBE LOCATIONS

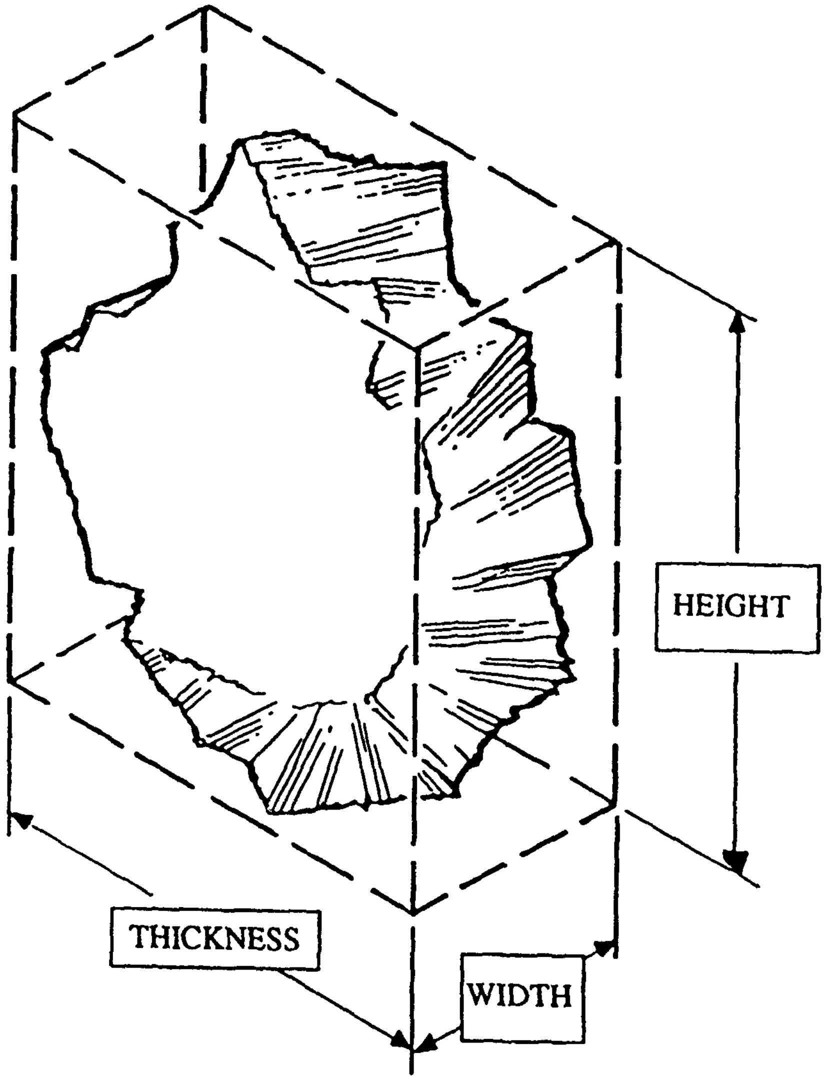


FIGURE 5. SHAPE FACTOR MEASUREMENTS

FIGURE 6. DEBRIS-NUMBER DISTRIBUTION: DISTANT RUNNER (full scale)

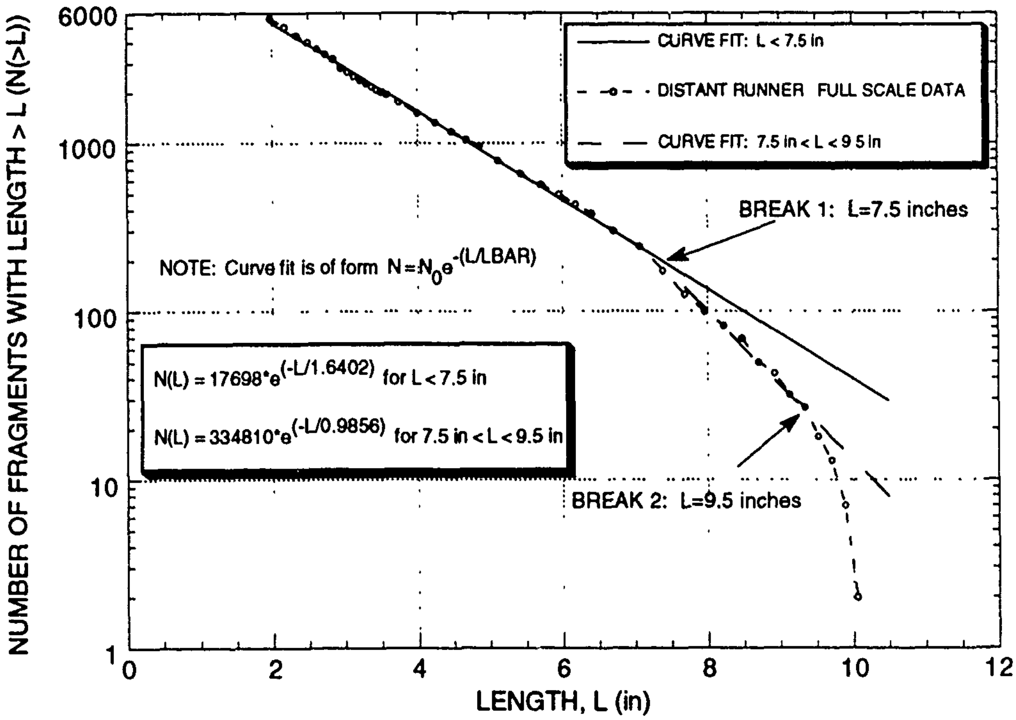


FIGURE 7. DEBRIS-NUMBER DISTRIBUTION: TENTH SCALE MODELS

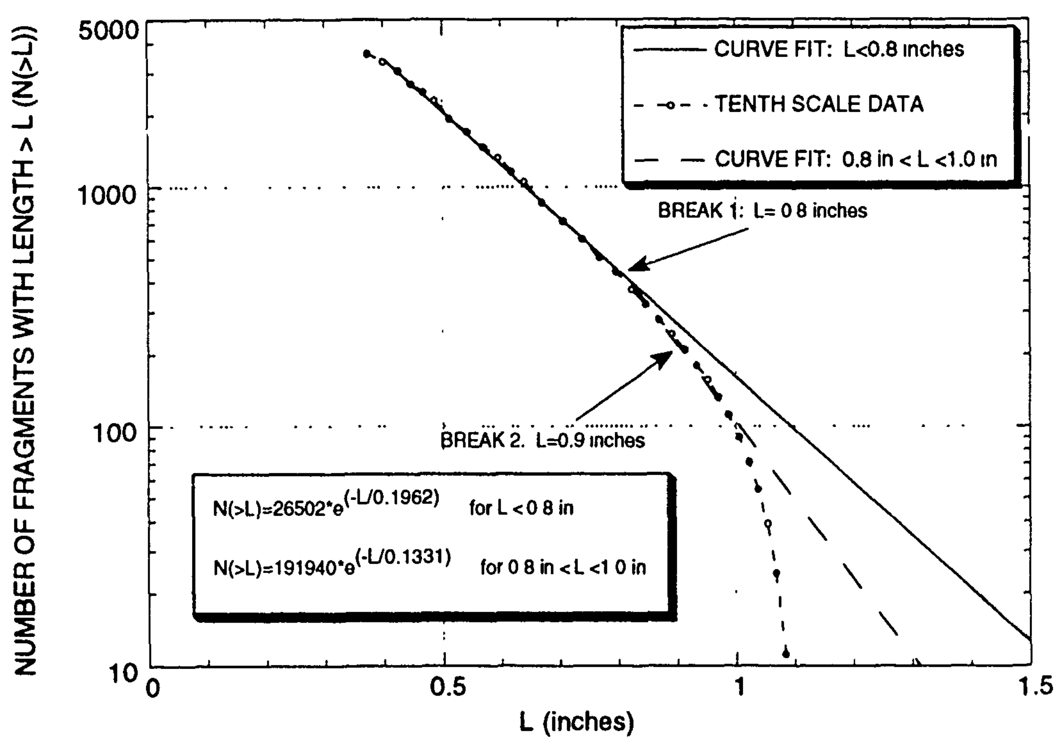


FIGURE 8. DEBRIS NUMBER DISTRIBUTION: QUARTER SCALE MODEL

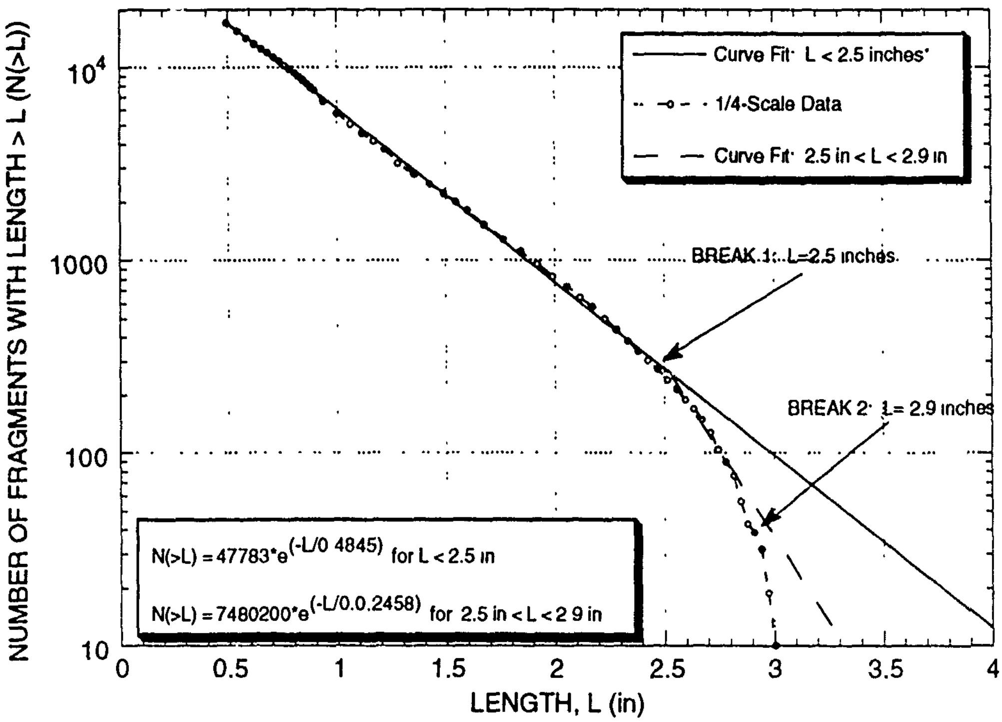


FIGURE 9. DESIGN VERSUS APPARENT SCALE FACTOR

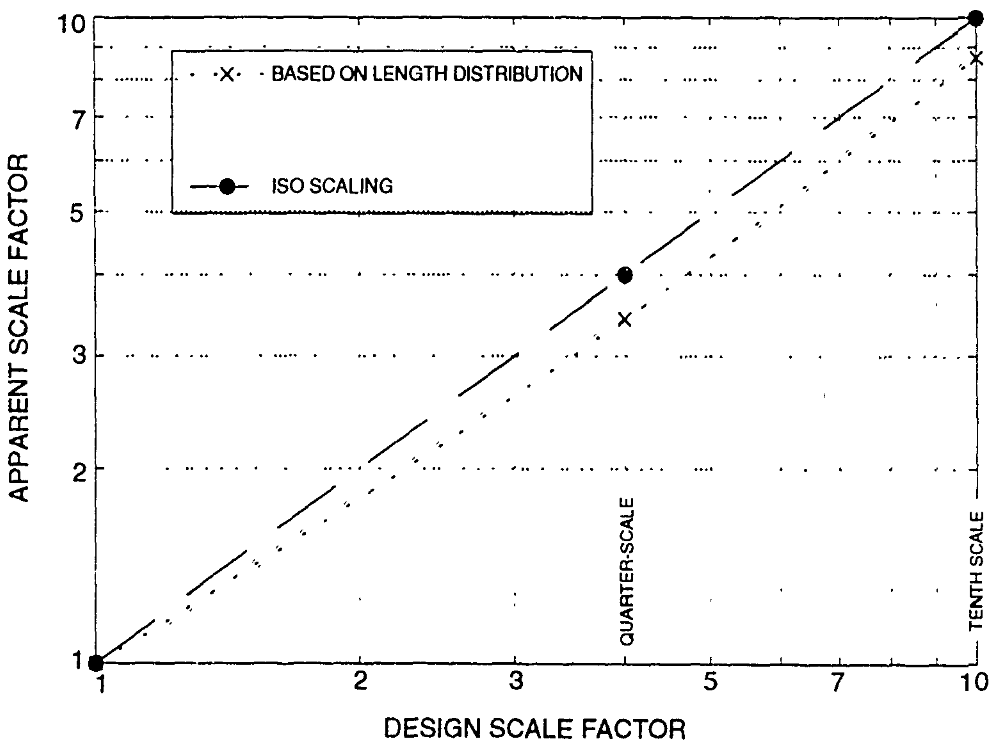


TABLE 1. FINAL DISPLACEMENT CUBE LOCATIONS

CUBE NUMBER	MATERIAL	DISTANCE HORIZONTAL (FEET)	DISTANCE VERTICAL (FEET)	HORIZONTAL ANGLE (DEG.MIN.SEC)
AC-1	ALUMINUM	159.6	-10.03	107.55.44
AC-2	ALUMINUM	126.14	-6.29	100.42.03
AC-3	ALUMINUM	not located		
AC-4	ALUMINUM	277.61	-15.48	90.03.09
AC-5	ALUMINUM	241.59	-12.55	88.24.14
AC-6	ALUMINUM	229.2	-12.08	86.37.49
AC-7	ALUMINUM	220.73	-11.75	82.42.55
AC-8	ALUMINUM	not located		
AC-9	ALUMINUM	37.75	-10.05	123.35.46
AC-10	ALUMINUM	98.76	-1.59	179.14.11
W-1	WOOD	147.52		83.55.00
W-2	WOOD	199.5	-10.36	91.07.00
W-2A	WOOD	169.02	-8.88	85.08.40
W-3	WOOD	248.55	-13.01	82.27.43
W-4	WOOD	254.09	-12.96	87.31.55
W-5	WOOD	211.31	-11.41	82.33.00

NOTES:

(1) Distances and angles are measured relative to the center of the shelter

(2) 0° is out the front of the shelter

(3) Because of the sloping terrain, the vertical displacements are included

TABLE 2. INITIAL CONDITIONS DETERMINED FROM DISPLACEMENT CUBE LOCATIONS

MATERIAL	IDENTIFICATION NUMBER	INITIAL HEIGHT (feet)	INITIAL ANGLE (°)	FINAL RANGE (feet)	LAUNCH ANGLE (°)	LAUNCH VELOCITY (ft/s)
Aluminum	5	0.2	0	242	5--10	130-160
Wood	5	0.2	0	211	1--9	130-160
Aluminum	4	2.5	15	278	0-14	130-160
Wood	4	2.5	15	254	10--25	120-160
Aluminum	3	6.6	35	not found	not calculated	not calculated
Wood	3	6.6	35	249	30-40	90-120
					10--20	130-150
Aluminum	2	7	50	126	30-70	60-80
Wood	2	7	50	broken	not calculated	not calculated
Aluminum	1	7.5	90	160	81-85	200-250
					85-87	250-400
					86-87	450-600
Wood	1	7.5	90	148	72-82	140-160
					78-84	180-200
					81-85	250-300
					83-88	300-500
Aluminum	6,7	2	15	229 & 221	12--18	110-130
					10 to -6	130-150
Aluminum	8	7.5	90	not found	not calculated	not calculated
Aluminum	9	7.5	90	138	30-50	50-70
					72-78	90-110
					76-78	110-130
					78-84	130-150
					80-84	150-170
					82-85	170-190
					82-86	190-210
Aluminum	10	4	45	99	20-60	50-70
					10 20	70-90

TABLE 3. AIRCRAFT SHELTER SCALE FACTOR DETERMINATION

EVENT	MEASUREMENT				
	LBAR-1 (in)	SCALE FACTOR	LBAR-2 (in)	SCALE FACTOR	
DISTANT RUNNER	1.6402	1.000	0.9856	1.000	
TENTH SCALE	0.1962	8.360	0.1331	7.405	
QUARTER SCALE	0.4845	3.385	0.2458	4.010	

EVENT	MEASUREMENT				
	BREAK 1 (in)	SCALE FACTOR	BREAK 2 (in)	SCALE FACTOR	AVERAGE
DISTANT RUNNER	7.5	1.000	9.5	1.000	
TENTH SCALE	0.8	9.375	1	9.500	8.660
QUARTER SCALE	2.5	3.000	2.9	3.276	3.418

TABLE 4. COMPARISON OF MODEL DATA WITH FULL SCALE HAZARD RANGES

EVENT	HAZARD RANGE (m/kg^1/3)		
	FRONT	SIDE	REAR
DISTANT RUNNER (OLD)	19.6	24.5	15.3
DISTANT RUNNER (PTN)	**20.1**	**21.4**	**17.3**
TENTH SCALE-1 (OLD)	26.88	28.15	18.38
TENTH SCALE-2 (OLD)	26.29	26.93	19.73
TENTH SCALE-3 (OLD)	24.90	30.17	15.41
TENTH SCALE-4 (OLD)	25.61	27.16	18.02
TENTH SCALE-5 (OLD)	25.90	27.99	20.49
TENTH SCALE-AVERAGE (OLD)	**25.9**	**28.1**	**18.4**
TENTH SCALE-1 (PTN)	25.93	27.29	20.00
TENTH SCALE-2 (PTN)	26.63	28.22	21.36
TENTH SCALE-3 (PTN)	27.18	32.22	16.79
TENTH SCALE-4 (PTN)	22.72	26.61	19.26
TENTH SCALE-5 (PTN)	28.66	30.44	22.71
TENTH SCALE-AVERAGE (PTN)	**26.2**	**29.0**	**20.0**
QUARTER SCALE (PTN)	**26.9**	**22.4**	**15.0**

NOTES:

(1) PTN is Pseudo Trajectory Normal Density

(2) OLD is the previous method of calculating debris density

"QUANTITY-DISTANCE PREDICTION METHODOLOGY FOR HARDENED AIRCRAFT SHELTERS--QDRACS"

by

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ABSTRACT

The subject work has been performed under Phase I of an SBIR (Small Business Innovative Research) program sponsored by Tyndall AFB under Contract No. F08635-91-C-0189. Technical manager for the Air Force was Captain Richard Reid. The effort concentrated on development of methods to quantify debris hazards from accidental explosions inside aircraft shelters. This includes shelters that are earth-bermed or earth-covered and those that are not. The Phase I effort addressed all aspects important to debris throw, including shock loading, gas loading, breakup, and throw. We call the prediction model QDRACS for Quantity-Distance Requirements for Aircraft Shelters. Included is new programming which uses image charges and ray-tracing of shocks for the specific geometry of an aircraft shelter. The shock load calculations are made at many locations over the interior surface, which is subdivided into a grid, for up to 20 munition stacks anywhere within the shelter. Existing data were utilized to determine structural breakup dependence on load intensity and the formation of small or large debris. Venting is calculated using the FRANG program as a subroutine to QDRACS, but with special treatment for defining vent area and vent perimeter based on the breakup pattern, and venting provided by the door. The velocity of all missiles is calculated based on contributions from both the shock and gas pressure loading. Debris dispersion is calculated using MUDEMIMP as a subroutine. Model results were compared to the Q-D criteria based on DISTANT RUNNER. Hazard distances, for Event 4, were predicted within 20% and, for Event 5, within 5% of the DISTANT RUNNER data.

BACKGROUND

Explosions inside a structure can result in the throw of debris and fragments along with the venting of blast pressures. These hazards must be considered when siting these facilities and occupied areas nearby. Debris are pieces of the destroyed structure which are thrown by the force of the explosion. The quantity of debris and the distances individual pieces are thrown are dependant on the construction of the building and the quantity of explosives involved.

The Department of Defense provides general siting criteria in DOD 6055.9 (Ref. 1) for debris throw from explosions in buildings. In certain situations, protection from fragments and debris is required, and the minimum distance is specified to be that at which the density does not exceed one hazardous fragment per 600 ft^2. A hazardous fragment or debris piece is defined as having an impact energy of 58 ft-lb or greater. If the distance at which this density occurs is not known, then DOD 6055.9 provides further guidance. For a Net Explosive Weight, NEW, of 100 lb or less, a distance of 670 ft, and for a NEW above 100 lb, a distance of 1,250 ft, are established as meeting the hazard criteria. These criteria are not specific to any particular structure type.

The DOD sponsored testing under the "DISTANT RUNNER" program (Ref. 2) and related analysis in an attempt to develop hazards criteria specifically for the third-generation Hardened Aircraft Shelter (HAS). This work established Quantity-Distance, Q-D, criteria directions to the side, front, and rear of a shelter. These criteria were adopted into DOD 6055.9, Chapter 10, "Theater of Operations Quantity-Distance," Section C, "Airfields Used Only By Military Aircraft." When the Net Explosive Quantity, NEQ, is greater than 50 kg and up to 5,000 kg, the safety distances are:

Front: $D = 20Q^{1/3}$

Side: $D = 25Q^{1/3}$

Rear: $D = 16Q^{1/3}$

where Q is in kg and D in meters. When the NEQ is 50 kg or less, there is a fragment hazard distance of 80 m to the front that is "nil" to the side and rear. These criteria do not address earth-covered or barricaded shelters.

DISTANT RUNNER was a successful program resulting in much valuable information concerning debris hazards from explosions in HAS's. Upper limit Q-D criteria were defined and adopted by the Defense Department Explosive Safety Board, DDESB, as mentioned. Others have performed related experimental and engineering studies. Of particular note is the Norwegian government which has funded several programs (Refs 3 and 4) and recent work related to debris hazards from accidental explosions occurring in operating building(s). The effort described in this paper involves development of a prediction tool to define debris hazards for more specific circumstances than that available in the past. Specifically, this is the first step toward development of software which will allow prediction of debris throw for a given situation and engineering analysis of design alternatives to reduce debris throw.

OBJECTIVE

The project objective (including work in future phases) is to develop a tool for the analysis and correction of debris hazards associated with accidental explosions inside Hardened Aircraft Shelters (HAS). The Phase I effort, which is the topic of this paper, was directed toward a study of existing methods, software and test data, and the development of "first-generation" predictive software. This Phase I effort also identifies future needs to complete the project goals.

A facilities planner must identify hazards for a given situation, and be able to investigate changes to correct the problem. Thus, the final software should allow the user to accomplish the following:

1. Evaluate debris dispersion and associated hazards present with an existing or planned HAS at a given site.
2. Evaluate site specific changes to the HAS to reduce debris throw around an existing shelter. This will include placement of barricades or earth covering.
3. Analyze the effect of weapon placement or arrangement in the shelter.
4. Analyze the effect of changes in explosive quantities in the shelter.

As an example, a facilities planner should be able to evaluate an existing shelter with the software. If the current situation presents unacceptable hazards, then he would evaluate various options. The software will define what portions of the shelter are causing the hazard. If the lower portions of the sidewall debris are being thrown the furthest, then the placement of barricades at some short distance is a viable option that can be modified as necessary. A similar solution would be to earth mound the shelter side-walls. The software must account for reduced debris velocity and recalculate throw distance. Another option would be to rearrange weapons placement in the shelter. If the original placement, for instance, were directly against or close-in to the shelter wall, then reduction in hazard distance could be calculated for a change in munitions placement.

If the software is to have the above features, it must be able to distinguish between debris originating for different portions of the shelter surface. The current goal is to define the concrete shell as a surface grid, perform separate analysis of each grid area (groups of elements), then add the results for a total hazardous debris distribution. This is a significant deviation from other methods which consider an entire wall or roof to behave uniformly as a source of debris hazards. The typical aircraft shelter is too large to justify the assumption that any surface will act uniformly under all circumstances.

The Phase I effort, which is reported in this paper, has achieved its goal of developing a first-generation software program utilizing new and previously developed routines. This software is named QDRACS (Quantity-Distance Requirements for Aircraft Shelters). QDRACS is a self-contained program and, when completed at the end of Phase II, will allow the planner to make Q-D evaluations. The Phase I effort includes the following steps.

DEBRIS HAZARD PREDICTION METHODOLOGY - QDRACS

The following paragraphs describe the elements of the QDRACS program, which are illustrated by the flow chart in Figure 1.

SHELTER GEOMETRY

The true geometry of a third generation HAS is that of an arch cross-section, which is currently idealized as the collection of five flat **surfaces**, with the front and end representing two additional **surfaces**, as shown in Figure 2. Each **surface** is then divided into rectangular **elements**, interconnected at corners by **nodes**. In Figure 3, the shelter is "flattened" to better show all elements. The shelter geometry is defined under an x,y,z orthogonal coordinate system (the same used to define positions of weapons stacks) with the origin located in the front left corner of the structure. The floor is not considered a source of debris for the purpose of this study, but it is a reflecting surface thereby increasing shock loads on other surfaces. The QDRACS has stored x,y,z coordinates of all nodes and hence the location of all element and surface corners. The program will calculate all element and surface midpoint coordinates. The program includes stored data on the concrete thickness and the depth of soil cover (if any). This information is not utilized in calculating the shock loading; however, it is used later in the calculation of shelter response to load and debris formation and throw. Variations on these parameters can be examined by changing the data file.

SHOCK LOAD PREDICTION ON INTERNAL SURFACES

The adoption or modification of existing programs such as SHOCK (Ref. 6) or BLASTINW (Ref. 7) was felt to be inappropriate since they do not model a structure with the geometry of typical aircraft shelters. A shock load prediction program specific to HAS was developed using similar methodology where direct shocks and shock reflections off adjoining surfaces are accounted for through ray tracing from image charges. Also similar to BLASTINW, the method used will analyze multiple charge locations. At this time, however, QDRACS does not distinguish times of arrival of shocks from different munitions stacks or from reflections. Impulses of separate shocks are calculated, then added together and treated as a single impulse load.

A non-responding or rigid structure is assumed when calculating the shock load phase; hence, all surfaces are considered to remain intact and act to reflect the shock as if they were rigid. Later in the analysis of structural motion, individual elements are allowed to move under the shock load.

Shock pressures and impulses are calculated by a subroutine, which uses a data file for reflected airblast curve given in Figure 4-7 of the newly revised TM5-1300 (8). An interpolation scheme was programmed to determine values between points in the data file. The scheme is based on a spline curve fit to data points on each side of the value of interest.

The pressures and impulses calculated are for normal (90-degree) reflections. It is clear that not all arriving pulses strike normal to the surface, and oblique reflections occur. However, this is a very good approximation, at least to 39 degrees for strong shocks (the regular reflection angle limit) and at much greater angles for weak shocks. All strong shocks will be due to close standoffs, and thus relevant to elements near the charge, which means shallow angles. The use of normal reflected data for all predictions is reasonable and certainly conservative (will overpredict loads).

Each element will have numerous shock reflections calculated. The impulses for all shocks are summed. Summary of the shock load at the various elements is output. This provides the shock load distribution over the interior surface of the shelter.

GAS LOAD PREDICTION ON INTERNAL SURFACES

The existing program FRANG (Ref. 9), developed by NCEL for the prediction of gas loads in vented chambers was modified as a subroutine and incorporated into QDRACS. Before FRANG is called by QDRACS, the venting characteristics must be defined as input. These include vent area, vent perimeter (where leakage occurs), vent panel weight, and applied shock impulse. The following paragraphs expand upon the analysis steps involved.

The shelter surface area available for venting of gas pressures depends upon that which fails under load. Two modes of failure are examined: one where the slab is overwhelmed by intense shock load, causing breakup into small pieces (wall breach), and a second mode where slab failure occurs due to slab rotations and extensions, resulting in large missiles. Portions of the shelter surface may receive insufficient load to cause failure, which becomes important when considering a small explosive weight. A scan of the shock load on all elements is made to determine if the response will be breach failure, large slab failure, or no failure. A total failed area is calculated summing all failed elements. The front wall (doors) is considered to be unconstrained and free to move. The entire front wall area is always included in the vent area.

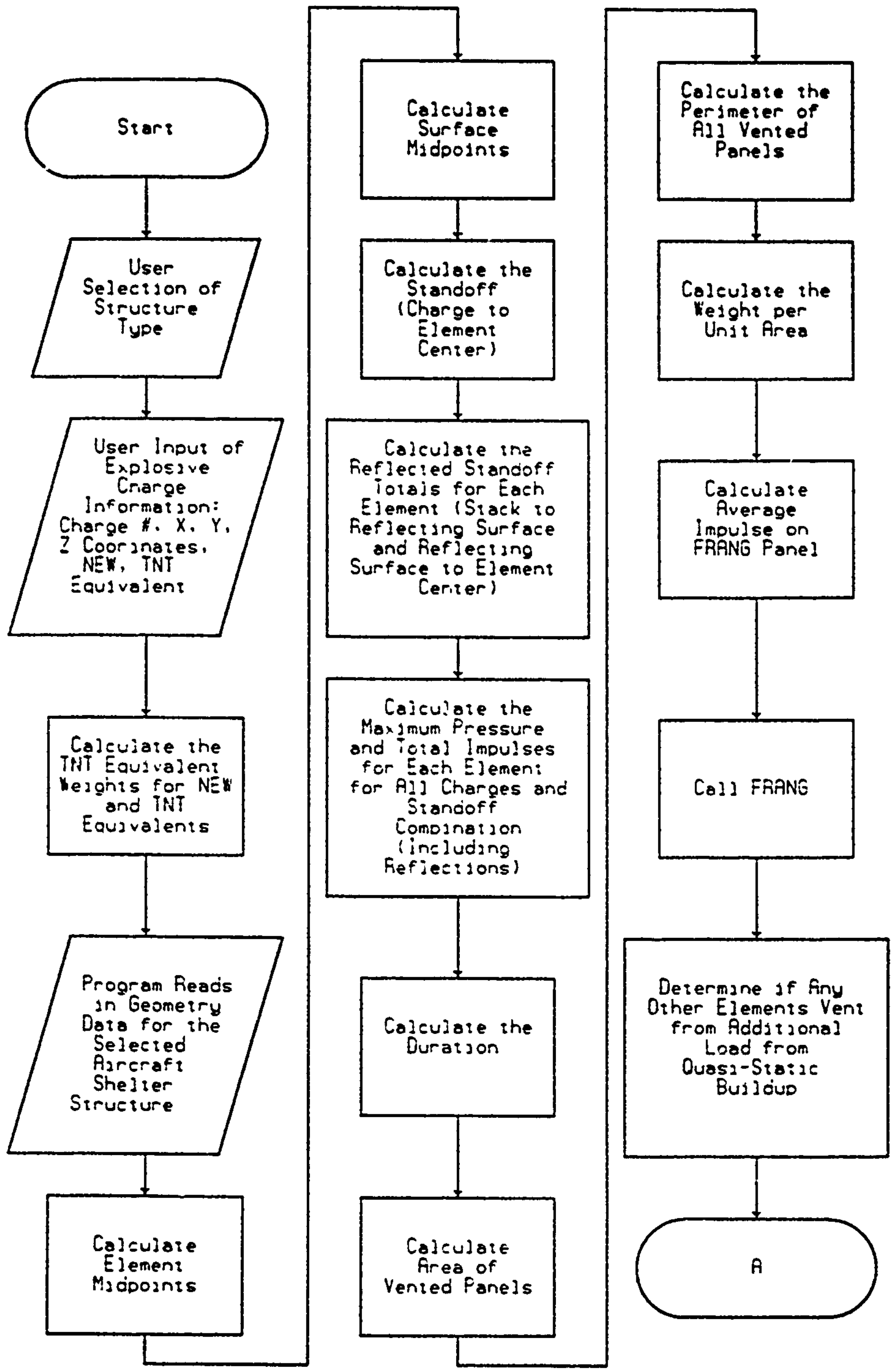

Figure 1. QDRACS Flow Diagram

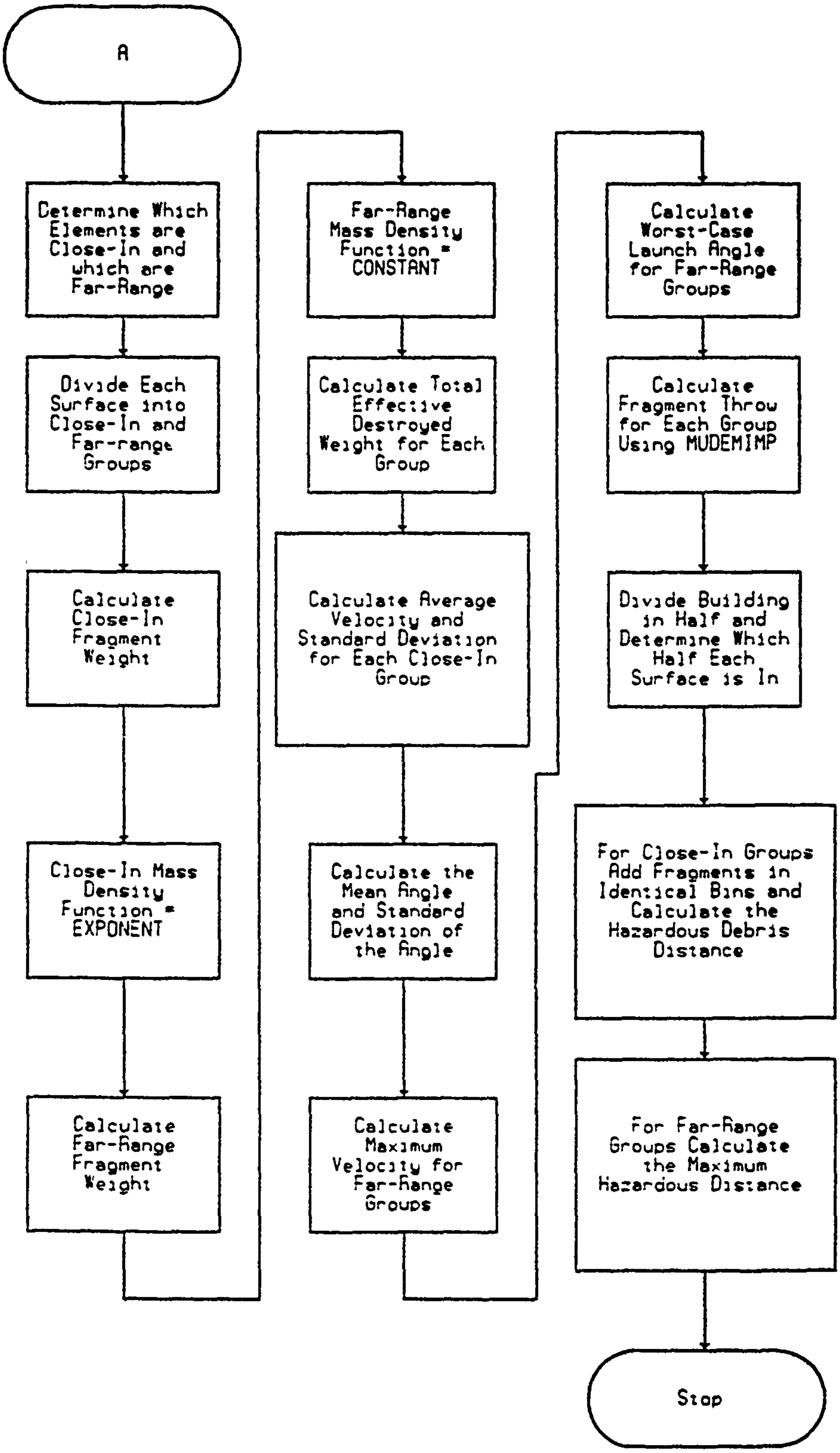

Figure 1. QDRACS Flow Diagram (Concluded)

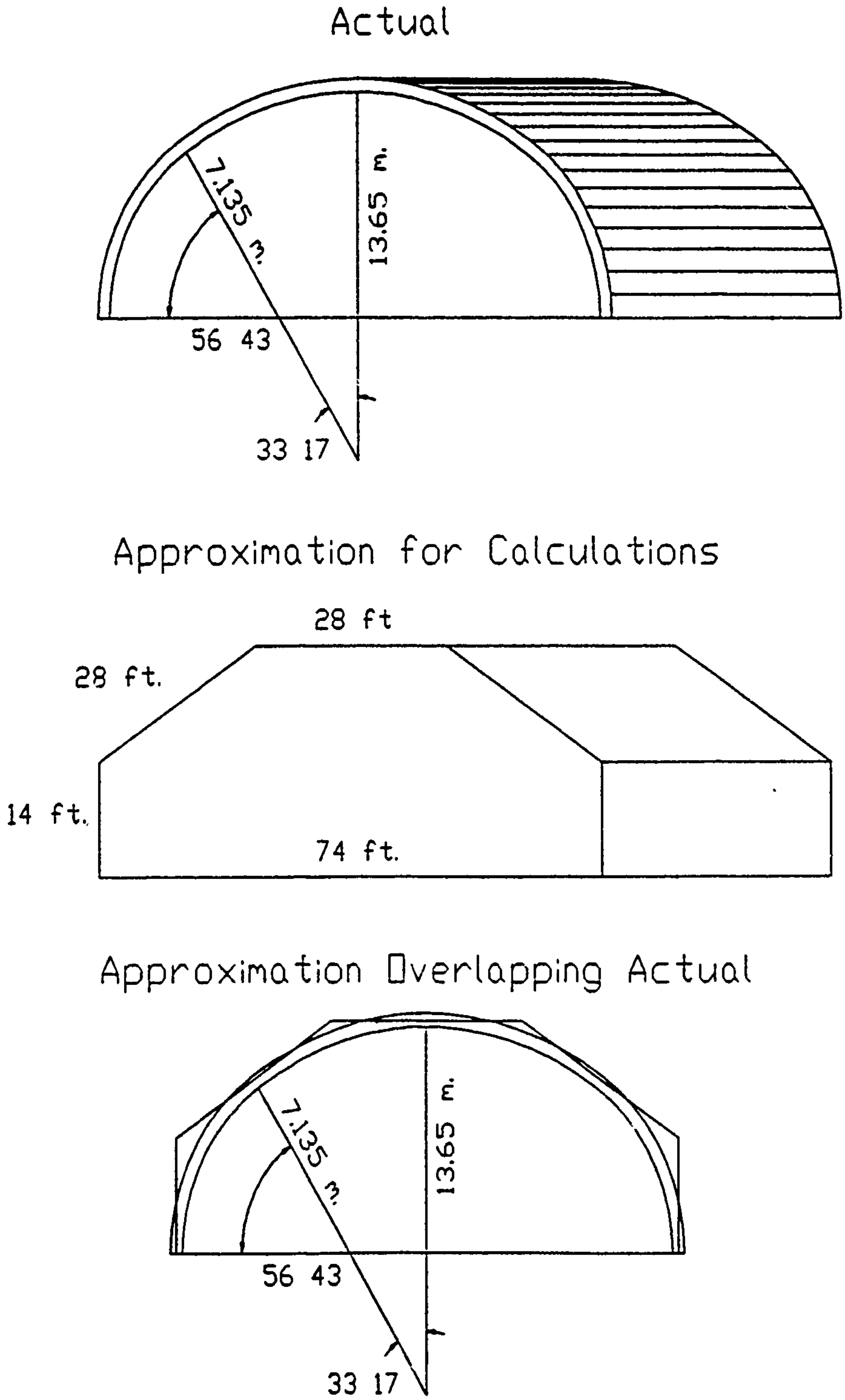

Figure 2. Approximate Shelter Geometry for QDRACS

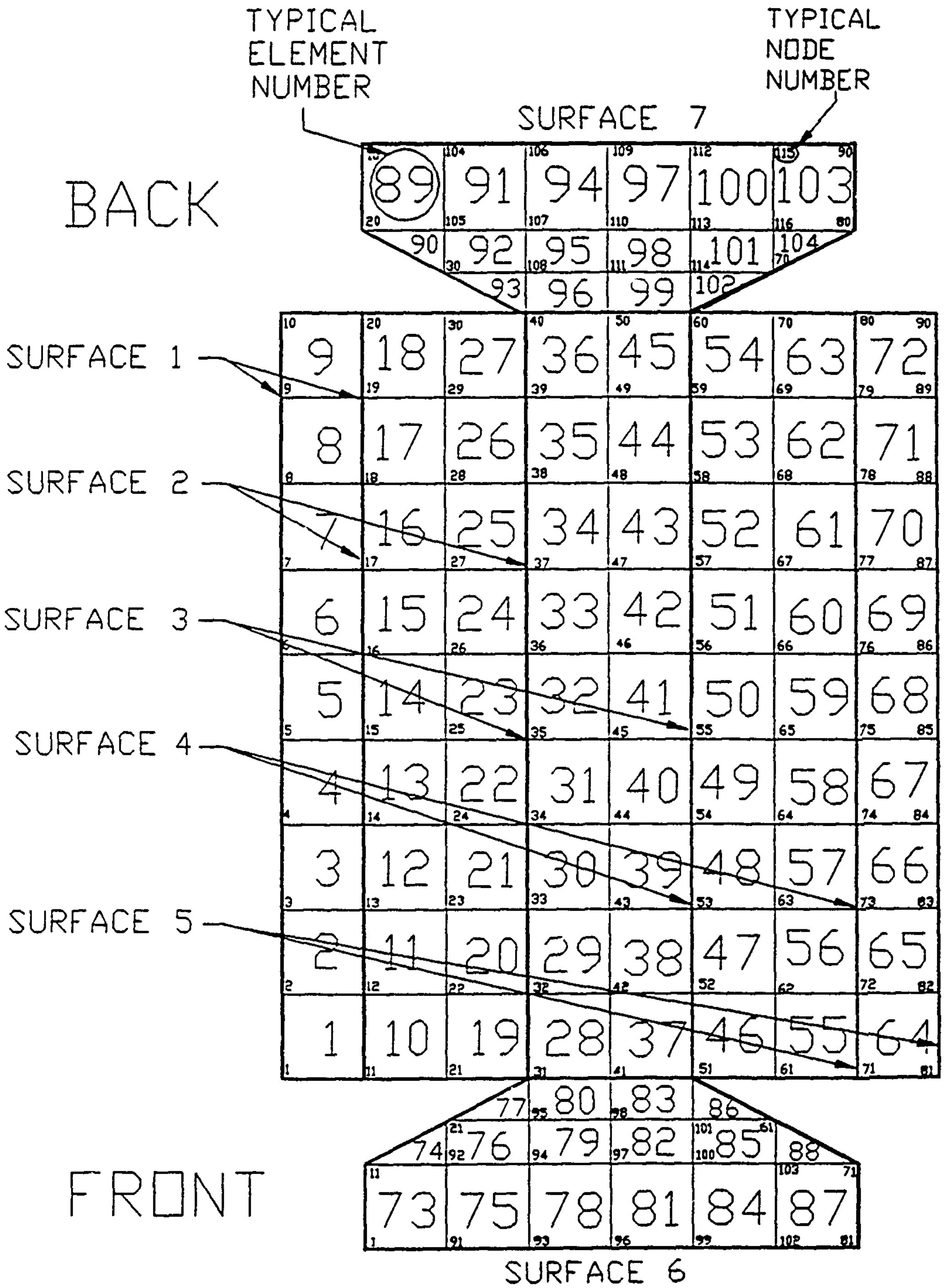

Figure 3. Grid, Surface, and Node Definition for Shelter

The vent area is considered to act as a single vent panel, as the FRANG program cannot analyze multiple vent panels. This is an improvement expected for the next phase of this study. To account for breakup of the shelter into multiple panels, the perimeter length term used in FRANG was calculated by considering the total perimeter length of the destroyed areas. Side-by-side elements, both of which failed, were not considered to contribute to the vent perimeter along the edge connecting the two. All elements were summed for this condition, and the perimeter length summed only for edges between failed and non-failed elements. A minimum perimeter was maintained, however, including all edges joining all surfaces.

FRANG requires input of the panel weight and applied shock impulse. The panel can include combinations from arch, front, and rear wall elements, which will have different thickness and receive different shock loads. Also, the user may want to investigate the effects of earth berming on the shelter, which can be accomplished with QDRACS. Berming will add mass to covered elements. To account for the distribution of weights and loads, an area weighted average was calculated for both. The area of each failed element was multiplied by the weight, and all were summed, then divided by the total destroyed area. The same type of averaging was made for shock impulse.

The QDRACS program then calls the FRANG subroutine to calculate gas load history. FRANG output includes the peak gas pressure, gas impulse to the time of critical venting (i_{AMAX}), and the total gas impulse (i_{TOTAL}). The maximum venting occurs when the vent panel has moved out to a distance where the perimeter area (perimeter length times distance) is equal to the panel area. At this point the venting is considered to be through an unobstructed area and continues until pressure drops to zero. The elements which make up the vent panel will gain additional velocity from the gas load. The i_{AMAX} is combined with individual shock impulses for all of these elements. Elements which did not fail due to the shock load did not contribute to the vent panel. To these, the i_{TOTAL} is combined with individual shock impulses. Once the appropriate gas impulse is added to shock impulse for each element, a second scan is made to determine if additional slab failures occur. This allows definition of all elements which will be considered for debris throw.

STRUCTURAL RESPONSE AND BREAKUP

As already mentioned, two modes of structural breakup have been considered in the QDRACS model. The first mode is where a slab is overwhelmed by intense shock load, causing breakup into small pieces, and the second mode is where slab failure occurs due to slab rotations and extension, resulting in large missiles. Each element is checked to determine which type of response occurs, and the resulting debris velocity is calculated.

The first mode is due to the combined effects of a stress wave transferred into the slab by the shock and the applied load overcoming the direct shear capacity of the slab. The stress wave is in compression until it reaches the outside free slab surface where it reflects as a tensile pulse. This causes spall if the tensile capacity of the slab is exceed. The depth into the slab where spall fractures can be formed depends on the duration and peak pressure of the stress wave. At the same time, the concrete is responding to direct shears produced by the applied load. Failure of the concrete results in a breach in the slab. Such a "breach" is characterized by small fragmentation of the concrete, which disengages and is thrown separately from the rebar. Criteria were selected for the project to define when this mode of response occurs. This was difficult due to the possibility of numerous separate stacks of weapons and reverberation of the shock within the structure. It was felt that breach would result only from shocks which occur relatively close in time. Gas load is not expected to be important to slab breach.

Hader (10) provides a comprehensive summary of published data relating to wall breach for both cased and uncased munitions. His work includes the effect of slab thickness. He plots data for scaled slab thickness, $T/W^{1/3}$, versus scaled standoff, $R/W^{1/3}$. The plots include 96 data points for bare charges, 31 of which were conducted by the author. Another plot of cased weapons data is given including 37 data points, 15 of which were conducted by the author. In his plots are division lines representing the onset of spall and perforation or breach. The author points out the difference in cased and uncased weapons effects, the cased resulting in much more severe damage. The curves by Hader are log linear and can be represented by the following equations:

	Cased Charges	**Uncased Charges**
Spall Limit:	$T/Q^{1/3} = 0.12(R/Q^{1/3})^{-0.4}$	$T/Q^{1/3} = 0.06(R/Q^{1/3})^{-0.565}$
Breach Limit:	$T/Q^{1/3} = 0.094(R/Q^{1/3})^{-0.4}$	$T/Q^{1/3} = 0.03(R/Q^{1/3})^{-0.565}$

For: T and R in m and Q in kg

These fits can be unscaled for the wall thickness of interest and converted to English units. This provides the following criteria for the arch portion of the structure, which has an average thickness of 28 inches. It was decided that choice of the spall limit would be too conservative, but that the perforation criteria were unconservative, the latter especially in the light that individual stacks and not the entire NEW are used with the criteria. The final choice is to use the average of these two limits. Thus, the following criteria were established for determining if breach occurs.

$$6.1 = W^{0.467} R^{-0.4}$$

This equation is for R in feet and W in pounds for the case of a 28-in. slab.

As stated, QDRACS will check each stack against each element to determine if breach will occur. If two stacks are close together relative to their distance from a particular element, then their effects are combined when comparing for breach.

If the load is not severe enough to cause breach, then gross slab rotations and flexure response can result in breakup. This type of response is expected to develop large missiles with the exception of rubble formed at hinge locations. A criterion was chosen to specify when this type of failure would occur. The criterion is based on bending response of a single element. If the combined shock and gas impulse is greater than 2,000 psi-msec, then this failure is determined to occur.

After the response mode of each element is determined, QDRACS then forms debris groups. This is accomplished by scanning all elements on a single surface to determine how many fail as small debris (due to close-in loading), how many fail as large pieces (due to far-range loading), and how many do not fail. The process is repeated for each surface. Two debris groups for each surface are formed, one containing all small debris and the other containing all large debris. These groups are used in the debris throw analysis. The small and large debris are isolated in this manner to allow separate calculations for each debris type.

DEBRIS VELOCITY AND MASS

Debris velocity and mass must be defined in a format compatible with the MUDEMIMP (Ref. 11) program which was chosen for debris throw analysis. It is widely recognized that the conversion of applied impulse into debris momentum gives conservative estimates of velocity. Reference 5 offers less conservative methods for velocity calculation based on empirical observations. While improvements over simple momentum calculations, these methods are primarily based on test data for explosive weights less than 300 lb and much, but not all, of the test data is for unconfined explosions where the shock load is the driving force. The situation for HAS is that the gas pressure load contributes to a significant portion of the debris velocity. In developing QDRACS, it was decided to use the impulse-momentum relationship, considering the combined shock and gas impulse, to calculate "maximum" velocity. We did use recommendations from Reference 5 for calculating average velocity and standard deviation for a normal distribution. These values are calculated based on the "maximum" velocity. For these debris, the average is equal to 60 percent of the maximum value. A normal distribution is used with a standard deviation of 14 percent of the maximum.

Debris mass is established by the two group types discussed earlier. The groups consisting of small debris from breached elements will have mass defined using criteria in Reference 5. This is corroborated by observations in the DISTANT RUNNER tests where debris sizes on this order were collected. An exponential mass density function is assumed with an average mass, m_{avg}, calculated by the following equation:

$$m_{avg} = 0.10\ [(\text{rebar spacing})^2\ (\text{cover thickness})\ (\text{density})]$$

The large debris resulting from slab rotations and extension was arbitrarily chosen to equal an entire element (Figure 3). Thus, the mass for these groups is considered to be a constant with zero deviation. The velocity for such pieces is taken as a constant as well.

DEBRIS THROW AND ROLL AFTER IMPACT

The program MUDEMIMP has been incorporated as a subroutine to QDRACS. The subroutine will be called for calculations on each debris group. There may be two groups for each surface. Each group is analyzed separately and results summed as appropriate to account for debris thrown in the same direction.

MUDEMIMP requires definition of trajectory angle, drag area, and drag coefficient distributions. These are all made using recommendations from Reference 5. The MUDEMIMP output gives the number of hazardous fragments (those with impact energies greater than 58 ft-lb) per 600 ft^2 are found at various distances from the explosion. This format is complementary to debris hazards criteria established by the DDESB.

The MUDEMIMP program was improved by Bowles, et al., (Ref. 5) to account for the distance traveled by debris after first impact due to roll or tumble. This feature is also used in the QDRACS calculations.

COMPARISON OF CODES WITH EXISTING TEST DATA

Comparisons have been made with the DISTANT RUNNER results for Events 4 and 5. Currently, QDRACS only predicts concrete missile throw to the sides of the shelter. The program evaluates response and debris throw from each side separately. The results for each side will be the same if the weapons are stacked symmetrically inside the shelter, resulting in the same loads on each side of the building. Otherwise, different results are expected.

The results of the comparison between QDRACS and DISTANT RUNNER are provided in Table 6. These calculations are for unbermed shelters, which were the type used in the Event 4 and 5 tests. These two cases were analyzed once again, but with an earth berm covering the shelter, with the results included in Table 6 for comparison purposes. The earth berm used in the analysis included a 2-ft cover on the roof, a 4-ft cover on the slant, and a 10-ft cover on the side.

TABLE 6. MAXIMUM HAZARD DISTANCE IN FEET

	DISTANT RUNNER	QDRACS (no earth cover)	QDRACS (with earth cover)
Event 4	820*	680	490
Event 5	1300*	1230	860

* Based on Q-D Criteria of 62 $W^{1/3}$

These results are reasonable, especially in light of the fact that the 62 $W^{1/3}$ criteria are based on an extrapolation of the DISTANT RUNNER test data. The researchers did not measure a debris density of 1/600 ft^2 at the distances above. The QDRACS code does predict greater throw distances, but at lower debris densities.

RECOMMENDATIONS

The QDRACS software, while adequate for a first phase study, requires improvement before it becomes a useful tool for quantity-distance predictions. General recommendations for the improvement of the prediction methods and software development are provided below. No particular priority has been given to these recommendations, as they are all considered important for improvement of the prediction model.

- Account for the response of multiple large missiles and the formation of multiple venting paths in calculation of gas pressure loads. Venting through breached areas may require use of a vent area ratio to account for the many leakage paths. Consider earth cover effect on venting.
- Improvement of the shock prediction should be made.

- An improved definition of structural breakup under various load conditions is necessary. Criteria for onset of breach and slab failure should be studied, along with classification of debris size distributions. Determine if soil cover affects structural breakup.

- Software improvements include

  - Additional geometry data bases for additional shelter types such as the joint-US/NATO or the Norwegian shelter.

  - Improved format for user input, allowing specification of earth cover, placement of exterior barricades, and specification of weapon types. For the latter, a data base of weapons types can be included in the software which has all NEW and TNT equivalence information. Thus, the user can call out weapons by their name, such as MK82, rather than requiring input of NEW and TNT equivalences.

  - Output can be customized to meet user needs.

- Currently, the program only accounts for DOD Hazard Class/Division 1.1 mass detonating weapons. Class/Division 1.2 items are not mass detonating. Also, many have 1.3 components which, while not affecting the shock load phase, are important in calculation of the gas loading phase. The program can be modified to account for differences in hazard classification of warheads and rocket motors.

- Debris dispersion calculations should be made for smaller regions of the shelter to track throw of debris from areas subjected to different loads. Summation of all dispersion calculations will be made to determine total hazard.

- The model needs to include hazards predictions in all directions (front, side, rear) and all possible fragment types. This includes primaries, metal ring, door frame, and others.

REFERENCES

1. DOD 6055.9, **Ammunition and Explosives Safety Standards**, Department of Defense Explosives Safety Board, July 1984.

2. Ward, Jerry M., **DISTANT RUNNER - Debris Recovery and Analysis Program for Events 4 and 5**, Naval Surface Weapons Center, White Oak Laboratory, Silver Spring, MD, 28 April 1982.

3. Moseley, Patricia K., and Whitney, Mark G., **Prediction of Blast and Debris from an Accidental Explosion Inside a Norwegian Aircraft Shelter**, Final Report, SwRI Project No. 02-5881, Joint Study Performed with Norwegian Defence Construction Service, NDCS Contract 13600/79/B/FBT II/AJ/AJ/720.9; Southwest Research Institute, San Antonio, TX, February 1981.

4. Riis, F., **Third Generation Aircraft Shelter. Debris Throw and Air Blast Caused by Accidental Explosions in the Ammunition Cubicle. Report III. Model Tests, Scales 1:20 and 1:100**, Fortifikatorisk Notat 149/80, November 1980.

5. Bowles, P. M., Oswald, C. J., Vargas, L. M., and Baker, W. E., **Building Debris Hazard Prediction Model**, Final Report for SwRI Project 06-2945, prepared for Bernard Johnson Incorporated under Mason & Hanger--Silas Mason Co., Inc., Contract H0760103, U.S. Government Contract DE-AC04-76DP-00487, November 1990.

6. Anon., **SHOCK Users Manual**, Version 1.0, Naval Civil Engineering Laboratory, Port Hueneme, California, January 1988.

7. Britt, J. R., Drake, J. L., Cobb, M. B., and Mobley, J P., **BLASTINW User's Manual**, ARA 5986-2, Final Report 2, Contract DACA39-86-M-0213, with U. S. Army Waterways Experiment Station, April 1986.

8. Air Force Manual AFR 88-22, **Structures to Resist the Effects of Accidental Explosions**, Revision 1 (Six Volumes), Department of Defense Explosives Safety Board, Alexandria, Virginia, November 1990.

9. Wager, P., and Connett, J., **FRANG User's Manual**, Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1989.

10. Hader, H., "Effects of Bare and Cased Explosives Charges on Reinforced Concrete Walls," Symposium Proceedings, The Interaction of Non-Nuclear Munitions with Structures, U. S. Air Force Academy, Colorado, May 10-13, 1983.

11. Huang, L. C. P., **Theory and Computer Program for the Multiple Debris Missile Impact Simulation (MUDEMIMP)**, Naval Facilities Engineering Command, Naval Civil Engineering Laboratory, Program No. Y0-995-01-003-331, June 1984.

AIRBLAST DAMAGE TO WINDOWS

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ABSTRACT

A model for predicting low-level airblast damage to residential areas has been derived from results of the 1963 Medina Incident, a 111,500-lL HE accidental explosion near San Antonio, Texas. From the reported distribution of window pane sizes, broken panes, and estimated incident overpressures, using appropriate statistical weighting in accordance with plate stress theory, it appears that a "typical" pane may be defined as a single-strength glass, 2 ft x 2 ft square (0.61 m x 0.61 m x 2 mm). If every pane exposed in San Antonio in 1963 had been replaced by a "typical" pane, the same total number should have been broken. Available population and housing census data allow normalizations which may be applied to other communities.

Other regional or stylistic architectures may require adjustment for typical pane definition, but this is not difficult. Thus, with an incident overpressure and a specified target community population of people, houses, or windows, the expected number of damage claims can be estimated. This process has been validated for the 1988 PEPCON accident at Henderson, Nevada, but complete details will not become available until litigation is settled.

BACKGROUND

Airblast prediction should consider three components: source, propagation, and targets [1]. A major uncertainty has been in predicting damage, hazard, or annoyance to targets from distant, low overpressure waves. Far field windows are generally considered to be the most sensitive structural element. In spite of their apparent structural simplicity, their transparent homogeneity, and their ubiquitous occurrence, their individual failure under blast loading is quite unpredictable. A review of factors which contribute to failure begins with stress analysis.

Glass failure under uniform pressure loading usually occurs on a convex surface under tension stress, rarely under compression on a concave surface. Although glass has very high theoretical tensile strength of 10 GPa [2], demonstrable with glass fibers, window plates show much lower practical tensile strengths of only 50 to 100 MPa, because of unavoidable surface flaws. For a simple rectangular plate under uniform loading, there will be a stress maximum at the geometric center with concentration lobes extending to the corners [3], as shown in Figure 1. Maximum stress will be proportional to total load (pressure times area) and inversely proportional to plate thickness [4]. It will be reduced somewhat by membrane stress effects in large plates, and by plate aspect ratios in comparison with square plates. There sometimes appears a modest difference in ultimate breaking stress between plate glass and ordinary window glass. Float glass technology appears to obscure this difference.

Contrary to ususal perceptions, edge defects from cutting, handling, or mounting are not very important because they occur near areas with minimum loading stress. Most critical is size and location of microscopic surface flaws, where loading failures originate. Thus, failure of a specific plate depends on its particular random set of flaw sizes and locations, and how they coincide with stress contours. Overall, failure stress appears to follow a Weibull distribution [5] of three parameters, with a very good approximation made by a log-normal distribution of two parameters: the geometric mean and geometric standard deviation of breaking load. Plate theory clearly shows inverse dependence of maximum bending stress on plate thickness, but some glass test empiricism has clouded this issue [6]. For very thick glass, some excessive failures have been observed, but they are most likely internal failures and not representative of most window glass performance.

In many incidents of large plate failures, glass broke outward, rather than inward under direct blast pressure loading. This appears to violate plate theory but actually represents dynamic amplification of load [7] under

plate recoil, particularly when it is in phase with the negative pressure phase. For large plates, dimensioned in meters, this dynamic amplification may exceed a factor of two.

Surface flaws result from manufacturing processes, from handling and transport for installation, and then from sandstorms or larger wind-borne missiles, as well as abrasive cleaning. One might expect an outdoor surface to be most vulnerable, and it usually is found to be the weaker surface, but in some notable instances the inside surface has been found weakest. Some experiments have shown that water can weather and weaken glass surfaces; yet other laboratory tests have shown that water may partially dissolve and re-deposit some glass in critical flaws to heal them. None of this is easily predicted.

AIRBLAST LOADING

Incident airblast overpressure predictions should be based on gaged values, with side-on gage aperture, to avoid reflective confusion. For low overpressures in the far field, normal reflection may be assumed. Flow merging associated with strong shocks is generally neglected. Also, except for extreme atmospheric refraction conditions, explosion airblast waves travel almost horizontally. On encountering a facing structure, incident overpressure will be doubled by reflection. Sonic boom tests showed this effect [7]; they also showed that a rear building face would receive about half the incident overpressure while side-facing walls and windows would receive the incident overpressure.

For a typical explosion, however, surrounding communities would have randomly oriented structure walls and windows. An assumed relation is that

$$P(w) = P(i) \times 2^{\cos A}$$

where A is the angle of wave approach from the window pane normal, as graphed in Figure 2. Randomized structure orientation and an effects-weighted integration around the azimuth circle gives an average reflection factor of about 1.32 [8]. Apparently, most first-story panes do not receive any significant additions from ground reflection. Whether this holds for second and higher building floors has not been established. This could also be complicated by multiple arrival times and phase- and frequency-dependent amplifications.

With complex structural planforms and neighboring buildings, there will be anomalous reports of damage in otherwise unlikely spots. In one example from WSMR, blast-facing windows were not broken in a near-cubical radiosonde recording building (SOTIM-3). On the far side, however, an identical sash had two (of three) panes broken by a DNA test explosion. It thus appeared that waves diffracted around the two sides and top of the building added to more than double the incident overpressure, which did not break any glass on the front face. Another example, from the 1963 Medina Incident [9], which will be detailed later, showed window damage in an interior corner store of a shopping mall, behind a building which was struck nearly face-on by the blast wave.

WINDOW DAMAGE PREDICTION

Statistical failure rates can be predicted for specified panes, given these factors. But making such detailed evaluations for each of a multitude of panes in any significant community, with roughly 19 panes per capita, presents a formidable computer task. Empirical damage relationships to explosion blasts have been difficult to establish, for a number of reasons. Damage correlations from accidental explosions usually suffer from lack of necessary yield information; there may or may not be appropriate weather information available. Furthermore, damage information usually becomes quickly involved in litigation and not easily available to analysts.

One exception at Medina Facility, San Antonio, TX, in 1963, was an accidental explosion of an exactly-known explosive yield of classified weapon components, with a nearby and promptly obtained upper-air weather observation and government-paid damage claims records. Results from that incident have been summarized to show an empirical mean pane-breaking load of 7.5 kPa, with

a geometric standard deviation factor of 2.5, shown in Figure 3 [9]. At -1 "sigma", 15% of panes would break from 7.5/2.5 = 3 kPa; at +1 "sigma", 15% would not be broken at 2.5 x 7.5 = 18.75 kPa, etc. Also, consideration of San Antonio's pane size distribution and their failures allows estimation for a "typical" pane [10]. This turns out to be a 2 ft x 2 ft x 0.08 inch square pane of single-strength (SS) glass. If every San Antonio window had been replaced by such a typical pane, the same total number of panes would have been broken by that accidental explosion. This simple relationship also allows easy scaling to other panes. For example, a 1-foot square SS pane would have a mean breaking load of 30 kPa. For a 1/4" thick plate, 6 ft x 9 ft, mean breaking load would be about 5 kPa.

For a large community, normalizing to 1000 single-family residences averaging 1600 sq.ft. of floor area and (by building codes) 160 sq.ft. of windows (40 typical panes), there would be 40,000 panes. One broken pane should result from about 190 Pa overpressure, since probability is 0.000025, corresponding to -4.0 geometrc standard deviations. As the number of broken panes increases, however, there is a growing probability of more than one pane broken in some houses; the result is a smaller number of claims than of broken panes, as shown in Figure 4. Probabalistic adjustment follows the hypergeometric equation; this calculation involves large factorials evaluated by Sterling's formula.

In conclusion, a relationship is provided between incident overpressure and number of window damage claims per 1000 houses. It agrees remarkably well with claims from the PEPCON accidental explosion, Henderson, Nevada, 1988. Eventually, barring court action to suppress these findings, other damages as well as costs may be calibrated to window claims for general application.

REFERENCES

1. American National Standards Institute (ANSI), Estimating Air Blast Characteristics for Single Point Explosions in Air, with a Guide to Evaluation of Atmospheric Propagation and Effects, ANSI S2.20-1983, Acoust. Soc. Amer., New York, NY, 1983 (Reaffirmed 1989).

2. Persson, R., Flat Glass Technology, Plenum Press, New York, NY, 1969.

3. Wang, J., and J.R. McDonald, "Fracture and Stress Pattern Correlations in Window Glass Plates," Glass Research & Testing Lab., Texas Tech University, Lubbock, TX, Sep. 1986.

4. Ansevin, R.W., "Correlation of the DSR with the Strength of Glass of Different Compositions and Configurations," Report ML TED 64-180, Pittsburgh Plate Glass Co., Harmar Township, PA, Aug. 1964.

5. Weibull, W., "A Statistical Distribution Function of Wide Applicability," J. Appl. Mech., 18, 3, Sep. 1951.

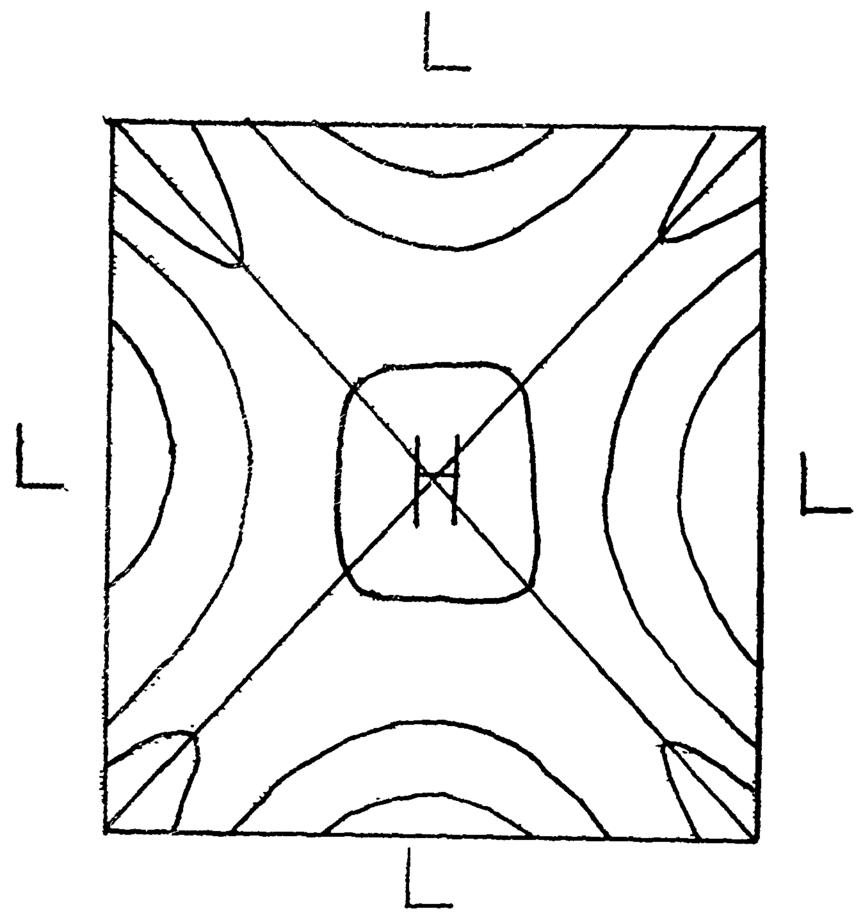
6. Bowles, R., and B. Sugarman, "The Strength and Deflection Characteristics of Large Rectangular Glass Panels under Uniform Pressure," Glass Technology, 3, 5, Oct. 1962.

7. Wiggins, J.H., Jr., Effects of Sonic Boom, J.H. Wiggins Co., Palos Verdes Estates, CA, 1969.

8. Reed, J.W., "Predictions of Nuisance Damage and Hazard from Accidental Explosions During Trident Missile Test Flights," SAND 79-0626, Sandia Nat'l Labs., Albuquerque, NM, Mar. 1980.

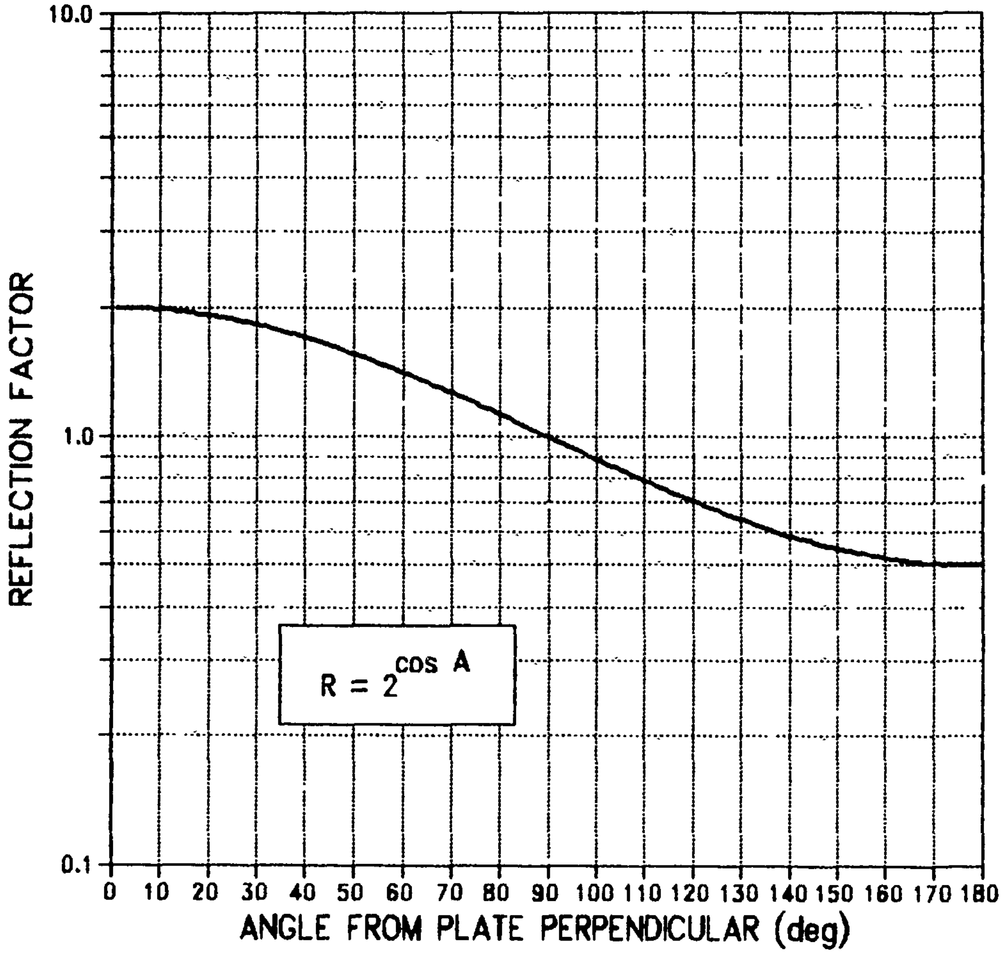
9. Reed, J.W., B.J. Pape, J.E. Minor, and R.C. DeHart, "Evaluation of Window Pane Damage Intensity in San Antonio Resulting from Medina Facility Explosion on November 13, 1963," Ann. N.Y. Acad. Sciences, 152, 1, Oct. 28, 1968.

10. Reed, J.W., "Analysis of the Accidental Explosion at PEPCON, Henderson, Nevada, on May 4, 1988," Propellants, Explosives, Pyrotechnics, 17, 88-95, 1992.



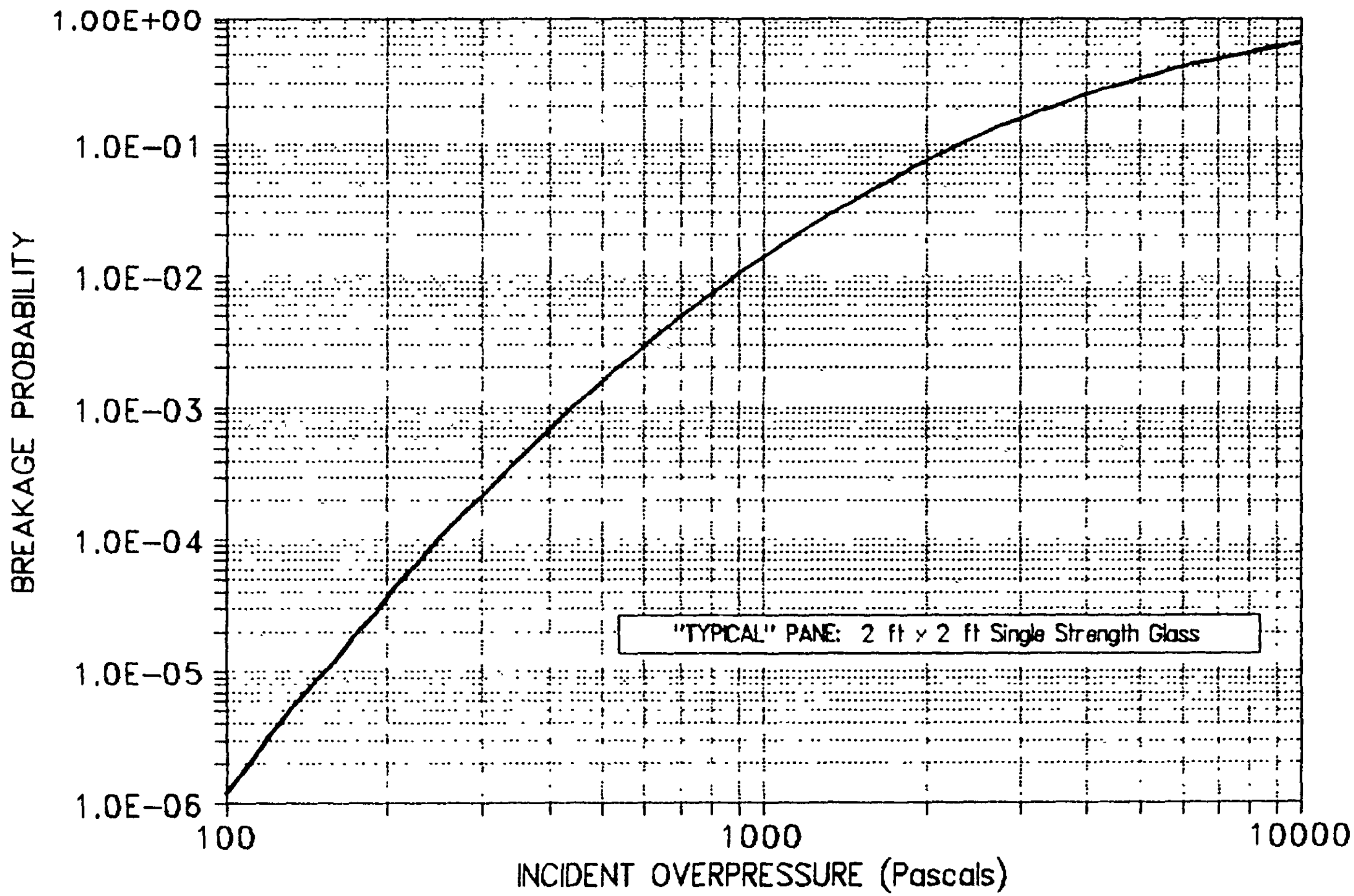
TENSION STRESS PATTERN IN SQUARE PLATE
UNDER UNIFORM PRESSURE LOADING

Figure 1.



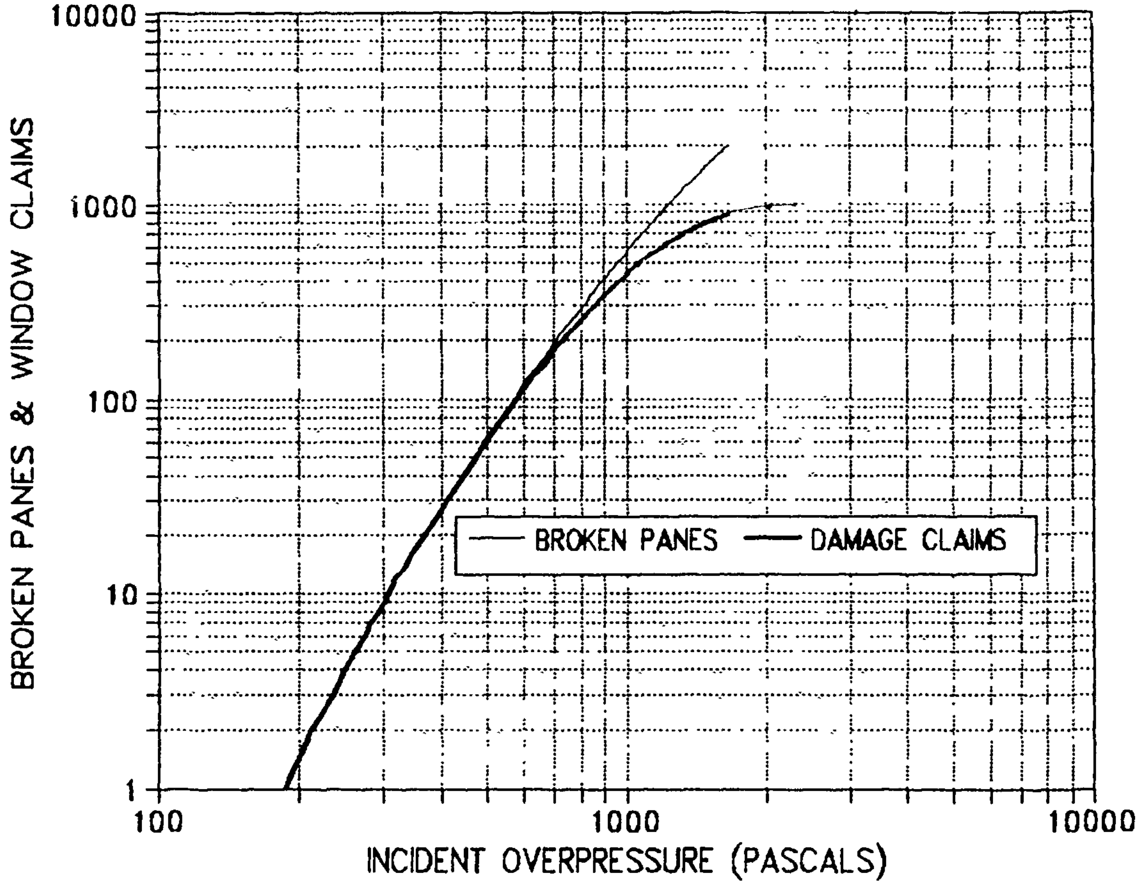
OVERPRESSURE REFLECTION FACTORS
VS. INCIDENCE ANGLE

Figure 2.



BREAKAGE PROBABILITY
AVERAGE SAN ANTONIO WINDOW PANES

Figure 3.



WINDOW DAMAGE VS. OVERPRESSURE
4 SQ.FT. SS WINDOW PANES
Breaks & Claims per 1000 Houses

Figure 4.

Measured Leakage Pressures from a Test Structure Through Covered and Uncovered Vent Areas

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1.0 Introduction

Explosives processing and testing bays are often constructed with a lightweight vent panel to allow quasistatic blast pressures to vent from the bay in the event of an accidental explosion. The use of a vent panel limits the damage caused to the bay during an explosion but it allows shock waves to propagate outside the bay and load nearby bays and/or inhabited areas. These blast pressures, known as leakage pressures, have been measured in a limited number of previous experimental programs. Most of these test series have concentrated on leakage pressures through uncovered vent openings from explosions occurring at the geometric center of the bay. During a recent test program conducted at Southwest Research Institute, leakage pressures were measured through both covered and uncovered vent areas from explosions occurring at various positions within the test structure. The test series, which was sponsored by the U.S. Department of Energy, was conducted to investigate the breakup and fragmentation of wall panels subjected to a large blast loads. However, the geometry of the test structure used during many of the tests was such that leakage pressures could be measured concurrently with wall breakup. This paper describes the leakage pressure measurements and compares the measured leakage pressures to those measured in similar testing programs from structures of different geometry with different charge placement and venting characteristics. The effect of a vent panel on the leakage pressures is also discussed.

2.0 Background

There have been a limited number of previous test programs where leakage blast pressures were measured. The most extensive program investigating leakage pressures was conducted at the Naval Civil Engineering Laboratory (NCEL) in 1975[1]. In these scale model tests, leakage pressures

were measured outside bays with two basic geometries (rectangular and cubic), bays with and without roofs, and bays with loading densities (the ratio of charge weight to room volume) varying from 0.009 lb/ft^3 to 0.25 lb/ft^3. Cylindrical charges of Composition B explosive with a 1:1 length to diameter ratio were used in the tests. Leakage pressures were measured through three types of uncovered openings; 1) an open side of a bay, 2) an open side and open roof, and 3) an opening within the roof (such as a short vent stack). Pressure histories were measured at a number of scaled distances along lines away from the front (in the direction of the open side), out the side, and out the back of the bays. Pressures were measured out the sides of the bays with partial openings in the roof. Based on approximately 100 measured blast pressure histories made during six tests, design curves (curve-fits to the data) were developed which predict leakage peak side-on pressure and total positive phase impulse outside bays through each of the three types of openings which were investigated. These design curves are included in the updated version of TM5-1300[2].

In 1967 three full scale tests were conducted in China Lake, California where leakage pressures were measured from explosive charges ranging from 1000 lbs to 5000 lbs of TNT through an open side and open roof of 40 ft x 20 ft x 10 ft bays. Information on these tests is summarized in Reference 1. The measured peak pressures were approximately 20% less, and the positive phase impulses were approximately 20% to 40% less, than those measured in comparable scaled tests in Reference 1 at NCEL. Possible reasons for this discrepancy given in Reference 1 include differences in charge shape and the range of loading densities and inaccuracies in scaling.

In 1986 the Terminal Effects Research and Analysis Group of the New Mexico Institute of Mining and Technology performed a comprehensive series of tests for NCEL[3] where leakage pressures were measured outside a missile test cell. Scaled tests (1:2.6 scale) were conducted at loading densities ranging from 0.005 lb/ft^3 to 0.045 lb/ft^3 where leakage occurred through a wall opening with a scaled vent area (the ratio of the vent area to the room volume to the 2/3 power) of 0.34. This scaled vent area is considerably less than that corresponding to a whole side of the test cell. Tests were conducted with no covering over the vent area and with panels over the vent area which had charge weight scaled areal densities ranging from 9 to 41 psf/lb$^{1/3}$. These areal densities correspond to panels which are much heavier than a typical light metal wall with insulation. In some cases the panels were recessed relative to the outer face of the test structure. Side-on pressure histories were measured at a number of scaled distances out the front (the direction in front of the vent opening), side, back, and out diagonally between the side and back of the test structure. This test data added to the base of existing information on leakage pressures by measuring the leakage pressures through a partial wall opening and measuring the effect of a vent cover on leakage pressures. The effect of relatively heavy vent panels was to significantly reduce the peak pressures (by a factor of 3 approximately) and impulse (by a factor of 1.5 approximately) out the front of the structure relative to the case of no vent covering, and to increase the pressure and impulse out the back and, in some cases out the side of the structure, relative to pressures through an uncovered opening. Evidently some of the shock wave, which would otherwise have been focused out the

front of the structure, was reflected towards the side and back by the vent cover as it was translating out from the structure. These data were used to help construct design curves for calculating leakage pressures around missile test cells.

Finally, a small scaled test program was performed at Los Alamos National Laboratory in 1986 to measure the leakage pressure history on the vent wall of the bay adjacent to a bay with an accidental explosion[4]. The testing was conducted because there was concern that the leakage pressures from a bay with an explosion could blow in the light vent walls on adjacent bays and the wall debris could cause detonation of explosives in the adjacent bays. One-eighth scale tests were conducted in which the light metal wall covering the vent area in the bay with the explosion was not modeled. The pressures and impulses measured on an adjacent bay vent wall in two tests were consistent (within 15%) with those predicted with the design curves in References 1 and 2. An axisymmetric hydrocode analysis, using the SALE computer code, was also used to model the leakage pressures and, on the average over the vent wall area, the calculated peak pressures generally agreed well (within 20%) with the measured values. However the calculated impulses were significantly less than measured values.

3.0 Test Program

During a recent test program conducted at Southwest Research Institute (SwRI), leakage pressures were measured through both covered and uncovered vent areas from explosions occurring within a test structure[5]. The test program was conducted primarily to define building wall breakup under blast loading so that an analytical model for predicting maximum hazardous debris distances from buildings subjected to an internal explosion could be developed. However, during many of the tests the surrounding area was instrumented with pressure transducers and leakage pressures were measured from explosions in a quarter-scale test structure shown in Figure 1. Quarter-scale reinforced concrete and masonry test walls were mounted in the back end of the test structure and the front end was either covered or uncovered depending on whether quasistatic pressures were required on the test wall. Several types of vent covers were mounted on the front of the box, ranging from 3/8-in gypsum panels, simulating a light frangible wall, to rigid steel plates which did not allow any venting. In the later case, the test panels failed catastrophically, so that their strength was of negligible importance, and they are considered to be the vent covers in this analysis of leakage pressures. The internal volume of the test structure is 187.5 ft^3 and the scaled vent area is 0.76.

The locations of the transducers used to measure leakage pressures are shown in Figure 2. Two PCB Piezotronics, Inc. 102A05 pressure transducers, which have a pressure range of 0-100 psi, were located directly in back of the test structure (gages Nos 01 and 02 in Figure 2) at 15 feet and 20 feet from the charge location. These two gages were mounted on a steel channel which was buried flush with the ground surface to prevent fragments from striking the transducers. PCB model 137A12 blast pressure probes, which have a pressure range of 0-50 psi, were located out the front side of the structure (Nos 03 and 04) at 15 foot and 20 foot standoffs and out the side of the structure,

in line with the front and back face of the test structure, at a standoff of 15 feet from the centerline of the structure (Nos 05 and 06). A few of the measurements made at locations out the front side of the structure used Model 137A11 probes which have a pressure range of 0-500 psi. Each PCB 137A12 probe was mounted in a holder at the same height as the charge. The pressure-time data were recorded real time using FM, Wideband II, analog tape recorders and were digitized later. Plots of pressure vs time were generated for each of the gages.

A total of 10 tests were performed where leakage pressure measurements were made. Useable pressure measurements were made at the front, rear and sides of the test structure for all tests with the exception of test Nos 1.8 and 2.1 where only the pressures at the back of the test structure were used. A table summarizing these tests has been developed and is included here as Table 1. The scaled vent panel weight listed in this table is the areal density of the panel divided by the cube root of the charge weight. Spherical C-4 explosive charges were used in the tests. The charge weights given in Table 1 are TNT equivalent weights and the standoff is the distance measured from the center of the charge to the test panel mounted in the back of the test structure.

Table 1. Matrix of Tests Where Leakage Pressures Were Measured

Test No.	Charge Wt. (lb)	Standoff (ft)	Venting Condition	Scaled Vent Panel Wt. ($psf/lb^{1/3}$)
1.3	2.5	.75	Open	-
1.4	2.5	.75	Covered	27.6
1.5	1.25 + 1.25 = 2.5	.75	Open	-
1.8	2.5	2.5	Covered	1.10
1.9	2.5	2.5	Covered	27.6
2.1	2.0	.75	Open	-
2.2	2.0	.75	Open	-
2.9	1.0	.75	Open	-
2.10	3.0	4.5	Open	-
2.11	.1875	.75	Covered	10.48
2.16	.1875	4.5	Covered	2.62
3.10	3.0	1.5	Open	-

Since the measurement of leakage pressures was not the major goal of the test series, all the factors which could influence the leakage pressures were not studied systematically and measurements were not controlled as well as they would be in a test program dedicated to the measurement of leakage pressures. In particular, two factors of the test program require some discussion. First, the back side of the test structure was actually a test wall which was typically, but not always, failed by the blast. Therefore, the possibility that some of the blast wave exited through the failed test panel in the back of the test structure and increased the leakage pressure to the rear of the test structure, relative to that which would be measured in a structure with a nonyielding backwall, must be addressed. The high speed film coverage of the test panels showed that the major portion of the panels began failing 15 milliseconds or later after the charge was detonated. This indicates that the shock wave had time to exit the test structure through the vent opening since the measured reflected pressure histories inside the test structure show very little impulse at times greater than 15 milliseconds. Also, the pressure data themselves do not indicate that the failure of the test panel on the back side of the test structure significantly affected the measured leakage pressures. This is true because the back panel failed during some tests, while in other tests it did not fail, but there is no trend within the data based on response of the back panel.

The other factor that may affect the scatter in the data is the accuracy of the measurement system. Most of the pressures measured out the front and side of the test structure used probes with a full-scale range of 50 psi. The electrical output of these transducers, as calibrated by the manufacturer, is linear within 2% of full-scale, which translates to 1 psi. The transducers used out the back of the test structure have a range of 100 psi. The factory calibrated these transducers from 0 to 10 psi and found the linearity over this range to be within 1%, which translates to 0.1 psi. Thus, the maximum expected scatter in the peak pressures as a result of transducer nonlinearity is in the measured pressures 1 psi out the front and side and 0.1 psi out the back. Since the peak pressures measured out the back of the structure are about one order of magnitude lower than the others, the scatter expected as a result of inaccuracies in the measurement system is the same (10% to 20% of the measured peak values) for all the pressure measurements.

4.0 Measured Leakage Pressures

Figures 3 through 8 show a comparison of the leakage pressures measured in the SwRI test program to those predicted from a fully vented three wall cubicle with a roof and a similar loading density using the method in TM5-1300[2] and Reference 1. The prediction curves used from References 1 and 2 were those from a rectangular structure with a shallow, wide footprint, or plan area, since it was the only structure tested at a loading density comparable to those used in this test series. This means that the predicted values, or solid lines, in Figures 3 through 8 represent data measured outside of a structure with a significantly different geometry than the narrow and long SwRI test structure. Here width refers to the distance between sidewalls and depth refers to the distance from the vent opening of the test structure to the backwall. The figures show peak pressures and scaled impulses measured out the front (at gages 03 and 04 in Figure 2), side (gage 05 nearest the vent area only), and back (gages 01 and 02 in Figure 2) of the test structure. The peak pressure

histories measured at the side gage in Figure 2 furthest from the vent area, which have approximately 50% to 65% of the peak pressures and 60% to 75% of the impulse of the pressure histories measured at the forward side gage, are not shown since there is no known prediction method to compare against. All scaled distances in the figures are measured on a straight line from the geometric center of the test structure to the gage location. The measured pressures from tests with a covered vent area are plotted with separate symbols so that the effect of the vent cover can be observed. Figures 3 through 8 show that, on the average, the measured pressure and impulse out the front for tests through uncovered vent areas match the predicted values well. They also show that the pressures and impulse through uncovered vent areas out the side of the test structure are approximately 25% less than the predicted values and the measured pressure and impulse measured out the back of the structure are significantly lower (approximately 70% less) than the predicted values.

The previously mentioned difference in the shape of the test structure from that used for the predicted values is thought to be the primary cause for the difference in the measured and predicted leakage pressures out the side and back of the test structure. It was noted in Reference 1 that structure geometry affected the measured leakage pressure and impulse measured out the back and side of the test structures in that test series. Lower impulses were measured out the back (approximately 30% lower) and out the side (approximately 15% lower) of a cubic structure at scaled standoffs between 10 ft/lb$^{1/3}$ and 20 ft/lb$^{1/3}$ as compared to those measured outside the wide, shallow test structure (width to depth ratio = 5:3) in comparable tests. Measured pressure and impulse out the front of these two structures from comparable tests were almost equal. Since the data measured out the side and back in this test series are also lower than those measured out the back of the wide, shallow structure in Reference 1, and the structure in this test program is much narrower and deeper (with a width to depth ratio of nearly 3:5) than the cubic structure in Reference 1, the differences between predicted and measured pressure and impulse in Figures 5 through 8 confirm the effect of structure geometry noted in Reference 1.

The reduction in leakage pressure and impulse measured out the back and side caused by the cubic shape in Reference 1 and long, narrow shape of the structure in this test series, as compared to the wide, shallow structure in Reference 1, can be characterized by a reduction factor. The fact that the reduction factor is greater for the data in this test series, where the structure was longer and narrower (the reduction factor is approximately 25% out the side and 67% out the back), than for the cubic test structure in Reference 1 (where the reduction factor is approximately 15% out the side and 30% out the back), indicates that the more the shape of the structure focuses the leakage pressure wave out the front, the lower the leakage pressures will be to the side and back. However, structural geometry does not seem to affect the leakage pressure and impulse out the front.

The other major difference between the tests conducted in Reference 1 and the tests in this test series is the charge location within the structure. In Reference 1 the charge was always located at the geometric center of the structure while the charge in this test series[5] was typically, although not always, located deep within the structure in this test series (see Table 1). It does not seem that this difference affected the measured pressure and impulse because the data from the few tests

where the charge was located near the vent opening fit the same trend as the rest of the data measured from charge locations near the backwall. A possible explanation for what seems to be a small effect of charge location is based on an understanding of the leakage blast waves that propagate from the structure. At the scaled distances where pressures were measured in the SwRI test series, the leakage blast wave consists of the incident wave, which propagates directly out the open end of the test structure, and reflections off the floor, roof, backwall and sidewalls of the test structure which also propagate out the open end of the structure and merge with the incident wave. Many of these reflections, and particularly that off the backwall, travel a shorter distance within the structure when the charge is located near the backwall than when it is located nearer to the vent opening. Therefore, the "average" standoff of the numerous reflections which, along with the incident wave, make up the wavefront of the blast wave outside the structure, is near the center of the test structure regardless of the charge location.

Figures 3 through 8 also show the effect of a vent cover on the measured leakage pressures. The figures show that the presence of a vent cover significantly reduces the measured leakage peak pressure and impulse out the front of the test structure and the peak pressure out the side of the structure compared to that measured with no vent cover. The reduction in impulse is slight out the side of the structure and there is no reduction in pressure or impulse out the back of the test structure. The reduction in pressure and impulse caused by the vent cover can be compared with those reported in Reference 3 from a partially vented structure (scaled vent area equal to 0.34 compared to the scaled vent area of 0.76 in the SwRI test series). For similar loading densities and scaled standoffs as those used in the SwRI test series, the peak pressure measured out the front of the test structure in Reference 3 was reduced by approximately a factor of factor of 3.5 and the impulse was reduced by approximately a factor of 2.5 by the presence of a vent panel. As Figures 3 and 4 show, the presence of the vent covers caused a comparable reduction in peak pressure and impulse out the front of the test structure in the SwRI test series. A direct comparison of leakage pressures measured through covered vent areas is not possible because of the difference in scaled vent areas used in these two test series.

The measured effect of the vent cover on leakage pressures out the side and back is somewhat different in the SwRI test series than that measured in Reference 3 at similar loading densities and scaled standoffs. The peak pressures and scaled impulses measured out the side of the test structure in Reference 3 were not significantly reduced by the presence of a vent cover. However, in the SwRI test series the reduction in peak pressure is approximately a factor of 2. The measured reduction in the scaled impulse is negligible and thus, in this respect, the two test series show similar results. Also, in Reference 3, it was found that pressure and impulse were typically increased out the back by the presence of a vent covering. The scatter in the pressures measured out the back in the SwRI test series is such that it can only be stated that the vent cover did not seem to cause any significant increase or reduction in the measured leakage pressures. On the average, the leakage peak pressure and impulse measured out the back through covered vent openings are largely equal to those measured through uncovered vent openings.

In summary, the comparison of leakage pressures measured out the front of the test structure in the SwRI test series to those measured in Reference 3 indicate that the effect of a vent cover on leakage pressures out the front is not influenced by scaled vent areas between 0.34 and 0.76. The comparison of leakage pressures measured out the back and side of the SwRI test structure to those measured in Reference 3 indicates that the effect of a vent cover on leakage pressures in these directions is influenced by the scaled vent area. The fact that the presence of a vent panel caused the leakage pressures to increase out the back and decrease out the open front of the structure in Reference 3 indicates that the vent cover is probably redirecting some of the leaked blast wave towards the rear of the structure as it translates out from the structure. The fact that the same trend occurs in the SwRI test series, which has a much larger scaled vent area, but that it is more moderate in that there is minimal or zero increase in leakage pressures out the back and side, indicates that the leaked blast wave is redirected to a larger extent when it is more focused by a smaller scaled vent opening. This seems to be true at least for the scaled vent areas between 0.34 used in Reference 3 and 0.76 used in this test series.

A final important observation is that the scaled weight of the vent cover does not seem to significantly affect the measured leakage pressures. As Table 1 shows, the test matrix includes a wide assortment of scaled vent cover weights but Figures 3 though 8 show that all the data measured from covered vent areas fit the same general trend. Figure 2-150 in TM5-1300[2] shows that the vent walls used in this test series are capable of reflecting almost all of the initial internal shock wave. Therefore, this may be the reason the scaled vent panel weight had no measurable affect on the leakage pressures in this test series. The reduction in leakage pressure out the front caused by a vent cover may also be largely due to the fact the wave must detract around the vent panel as it translates out from the structure. In this case it also makes sense that the panel weight would not be important. Also, the scaled vent cover weight and scaled recessed distance of the vent panel relative to the outside face of the structure did not seem to cause any consistent or strong effect on the leakage pressures measured through covered vent openings in Reference 3. This helps confirm the similar observation in this test series which is based on much more limited data.

Figures 9 through 11 show a comparison between the measured scaled arrival time of the largest measured leakage pressure pulse at gages in front, to the side, and in back of the vent opening with the scaled arrival time predicted by the TM5-1300[2] airblast curve for a hemispherical surface burst. The scaled distance used in the airburst curve is based on the line of sight distance from the actual charge location to the gage through the vent opening and, for gages in the back and side of the structure around the structure. These figures show that the time of arrival of the peak pulse through an uncovered vent opening can be predicted relatively well with this method. The figures also show that the vent panels significantly delayed the arrival of the peak pressure pulse. The fact that some of the scaled arrival times at gages out the back of the test structure through covered vent openings were not affected by the vent cover is due to the fact that, for these tests, the peak pulse arrived as an initial pulse in the train of blast pulses measured at this location, rather than as a later pulse as was typical. Therefore, this is an anomaly rather than a significant trend.

Figures 12 through 14 show some examples of measured leakage pressure histories out the front, side, and back of the structure through uncovered vent openings. The measured pressure histories out the front and side through uncovered openings are characterized by a single pulse which contains almost all of the impulse. The pressure history out the back is characterized by two to three pulses with significant pressure and impulse. The pressure histories out the back are better characterized by an isosceles triangle rather than the right triangle typically used to represent blast pressure pulses and their duration is significantly longer than the single pulse pressure histories out the front and side of the structure. The form of the measured pressure histories from uncovered vent openings in this test series are similar to those reported in Reference 1 from three-walled cubicles with a roof at similar scaled standoffs.

Figures 15 through 17 show some examples of measured leakage pressure histories out the front, side, and back of the structure through covered vent openings. The pressure histories measured out the front and side through covered openings are similar in form to those measured out the back through uncovered openings. It is possible that this similarity is due to the fact that the vent cover is an obstruction to the propagation of the leakage blast waves out the front and side of the structure in the same way the structure itself is an obstruction to the leakage blast wave out the back of the structure. The measured pressure histories indicate that such obstructions increase the distance required for the trailing pressure pulses from reflections within the structure to merge with the incident pulse that propagates directly out the vent opening

5.0 Conclusions

The following conclusions can be drawn from the analysis of the test data presented in this paper and the data from preceding test series discussed in this paper. In general, only trends in the data, rather than quantified relationships, can be concluded because of the limited amount of data that was measured.

1) Structure geometry does not significantly affect the leakage pressure and impulse out the front of fully vented structures with roofs at the scaled distances measured in both this test series and in Reference 1 (scaled distances greater than 10 ft/lb$^{1/3}$).

2) Structure geometry does seem to affect the leakage pressure out the side and back of fully vented structures. Based on data from Reference 1 and from this test series, the greater the width to depth ratio of the structure (depth is the dimension between the vent opening and the backwall-width is the dimension between sidewalls), the larger the leakage pressure and impulse out the side and back of the structure at standoffs measured from the center of the structure.

3) Charge location within the structure does not seem to affect the measured leakage pressures.

4) The presence of a panel over the vent wall (with a scaled vent area of 0.76) significantly decreased the peak leakage pressure (by a factor near 3.5) and positive phase impulse (by a factor near 2.5) out the front of the test structure. A vent panel decreased the peak leakage pressure out the side (by a factor near 2) of the structure but did not significantly decrease the impulse. The average measured leakage pressure and impulse out the back of the structure was not affected by the presence of a vent panel.

5) The effect of the vent cover on leakage pressures stated in number 4 is only consistent with the effect measured out the front of the covered vent openings in comparable tests in Reference 3, where the scaled vent area was only 0.34. This indicates that the effect of a vent panel on leakage pressures out the side and back of the structure is dependent on the scaled vent area.

6) The scaled weight (areal density divided by the cube root of the charge weight) of the vent panel does not seem to affect the leakage pressures outside the test structure, particularly those measured out the front and side. Because of the scatter in the data out the back, no definite conclusion can be drawn for this case.

7) The scaled arrival time of the main pulse of the measured leakage pressure histories through uncovered vent areas could be predicted well using the scaled line of sight distance from the charge to the point of interest and the airblast curves for a hemispherical ground burst in TM5-1300[2].

6.0 References

1. Keenan, W.A. and Tancreto, J.E., "Blast Environment From Fully and Partially Vented Explosions in Cubicles." Report No. TR-82?, Civil Engineering Laboratory, Naval Construction Battalion Center. Port Hueneme, CA, November 1975.

2. Design Manual Army TM5-1300, NAVFAC P 397, and AFM-88-22: Structures to Resist the Effects of Accidental Explosions, Department of the Army, Navy, and Air Force, Washington, DC, 1990.

3. Tancreto, J., Missile Test Cell Design Load and Safe Siting Criteria, Technical Memorandum, No. 51-86-15, Naval Civil Engineering Laboratory, Port Hueneme, CA, August 1986.

4. Smith, P.D. and Crawford, T.R., "Effects of Explosion on Adjacent Bay Blowout Walls," from Minutes of the 22nd Explosive Safety Seminar, August 26-28, 1986, Anaheim, CA, pp. 105-118.

5. Bowles, P.M., Oswald, C.J., Vargas, L.M. and Baker, W.E., "Debris Hazard Evaluation, Task 3: Test Program and Predictive Model Refinement," Draft Final Report, prepared for Bernard Johnson, Inc., under Mason & Hanger Silas Mason, Inc., Contract H0760103, U.S. Government Contract DE-AC04-76DP-00487.

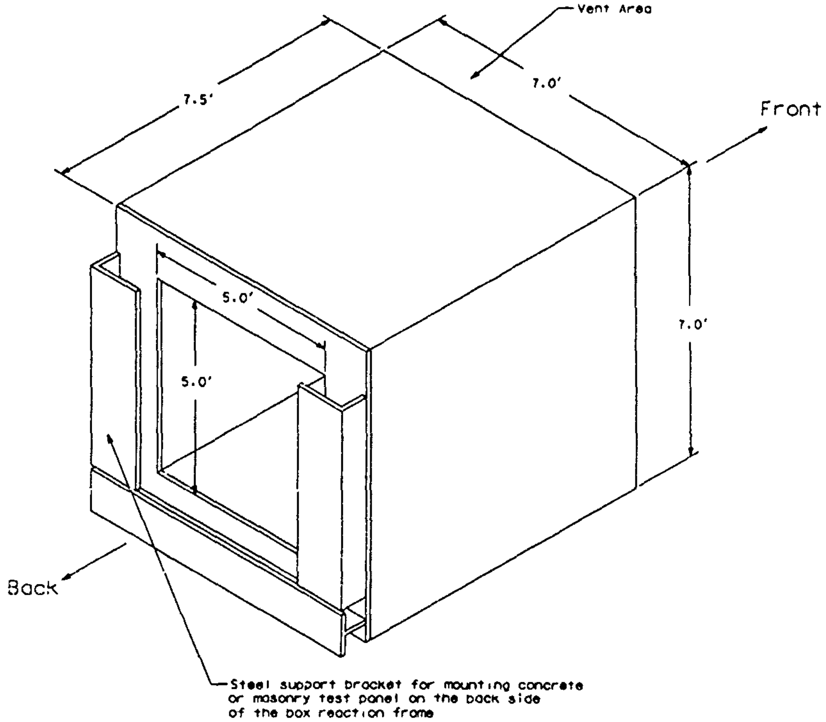

Figure 1. Test Structure Showing Mounting Bracket for Test Panel on Back Side and Vent Area on Front Side

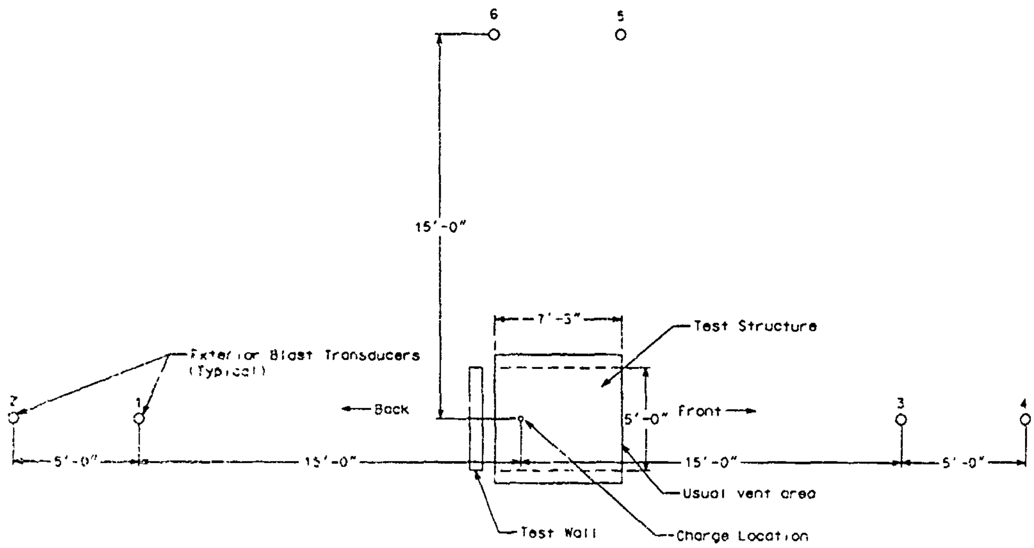

Figure 2. Plan View Showing Locations of Blast Pressure Transducers (Nos. 01 through 06) Used to Measure Leakage Pressures from Test Structure

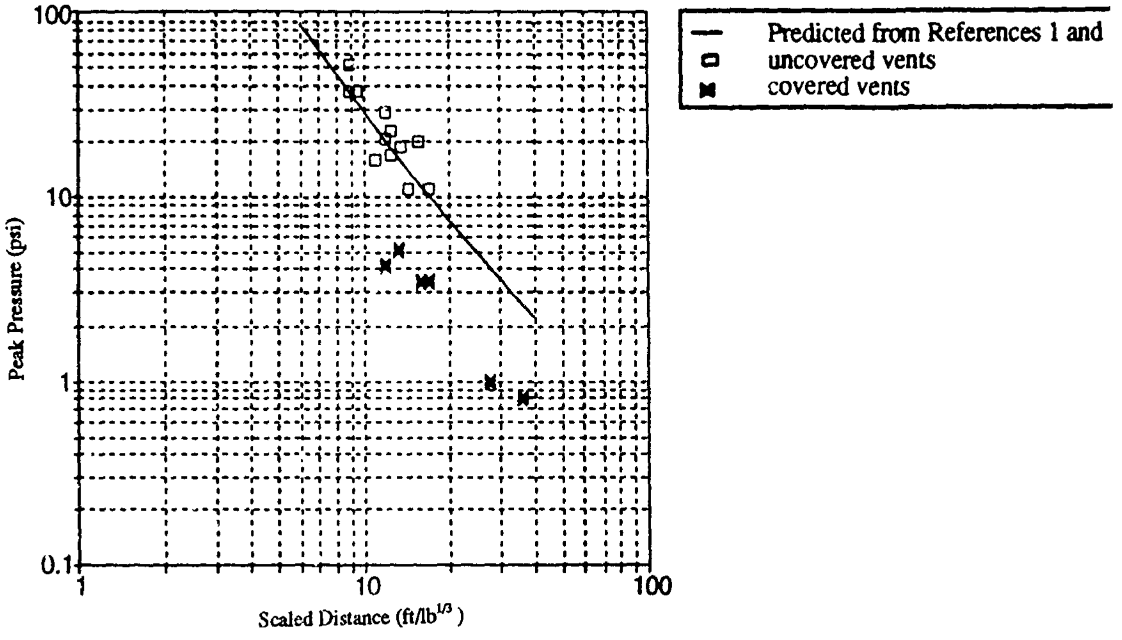

Figure 3. Peak Leakage Pressures Measured Out the Front of Test Structure Compared to Predicted Values in References 1 and 2

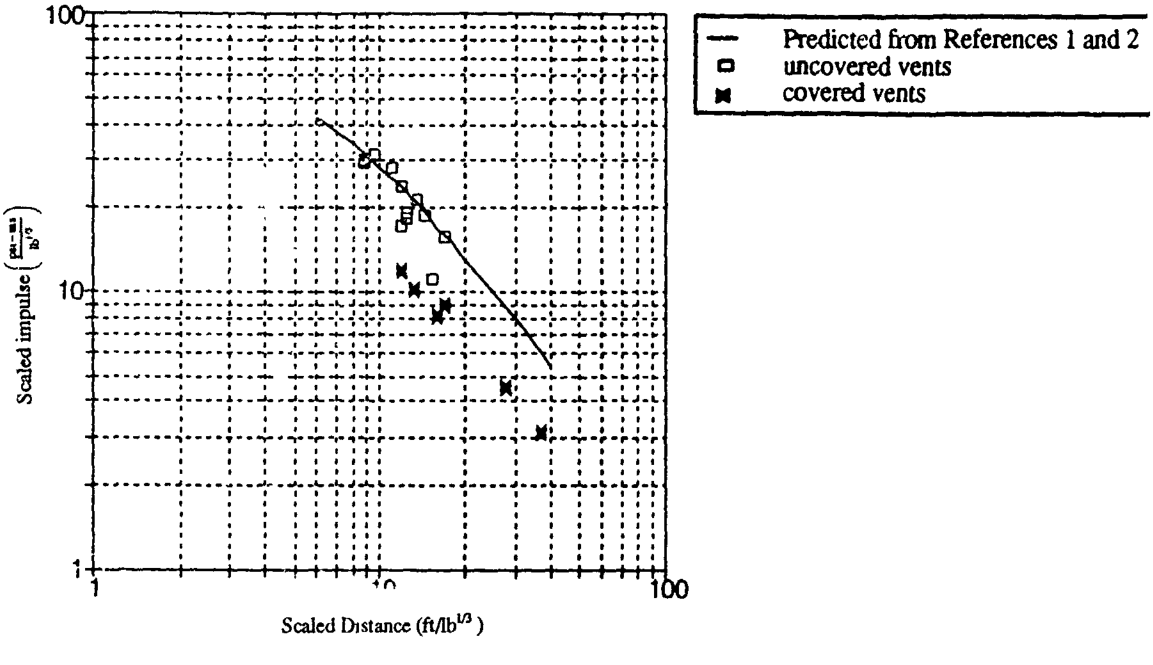

Figure 4. Scaled Leakage Impulse Measured Out the Front of Test Structure Compared to Predicted Values from References 1 and 2

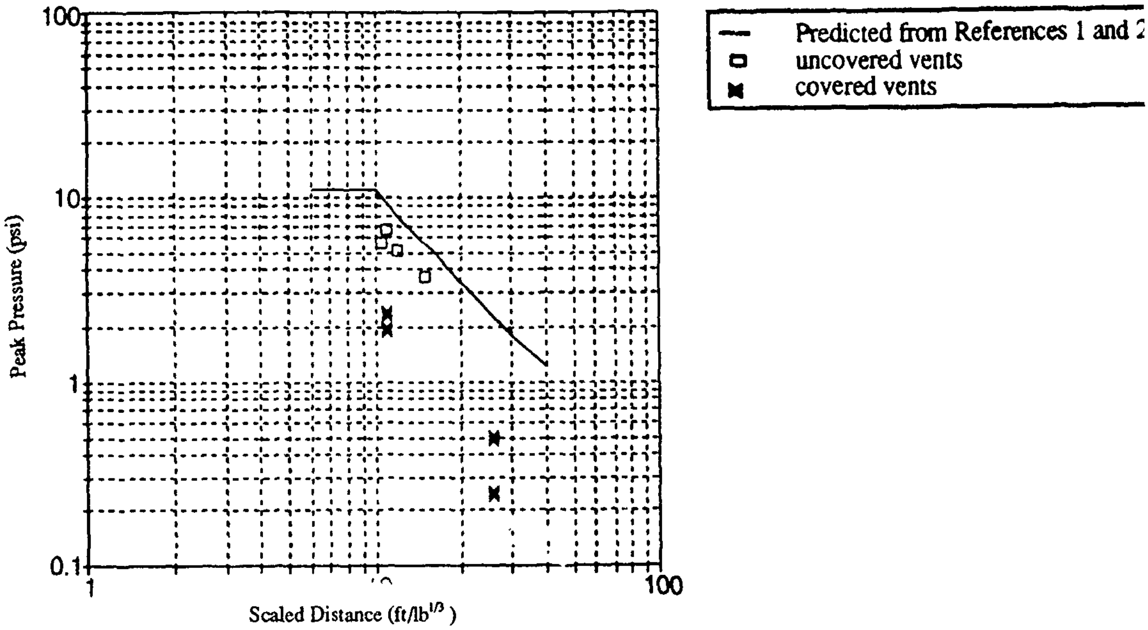

Figure 5. Peak Leakage Pressure Measured Out the Side of Test Structure Compared to Predicted Values in References 1 and 2

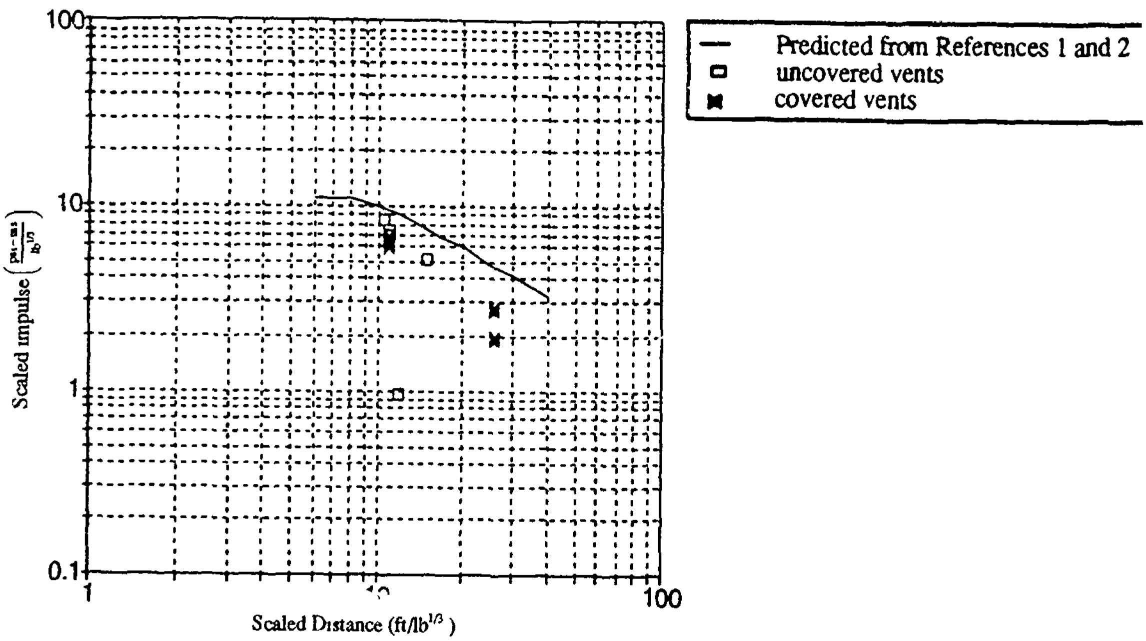

Figure 6. Scaled Leakage Impulse Measured Out the Side of Test Structure Compared to Predicted Values in References 1 and 2

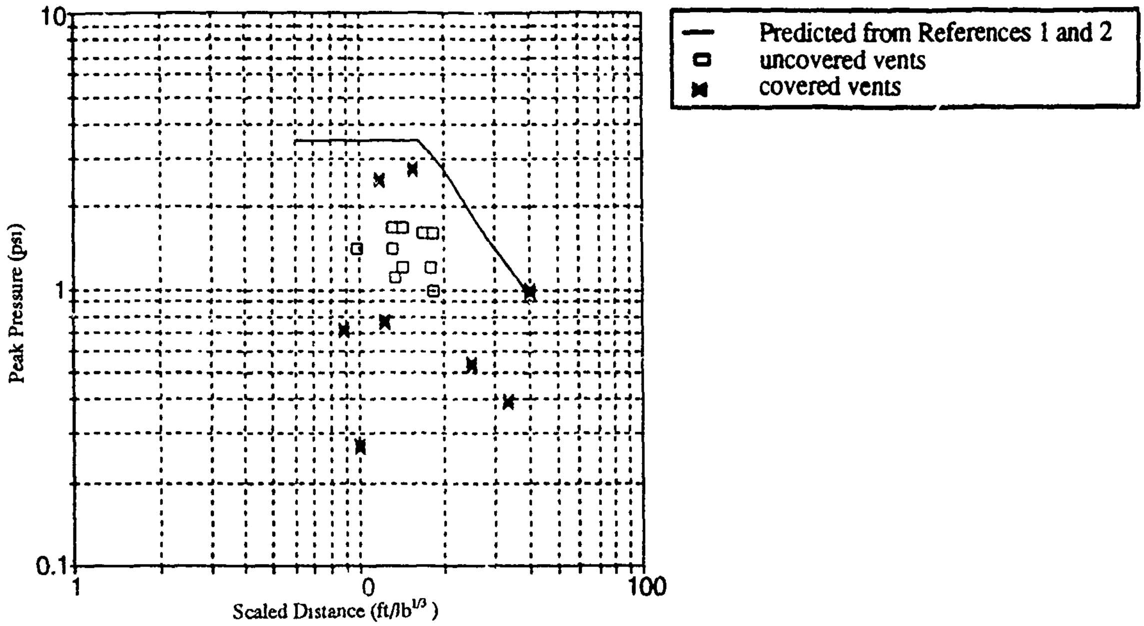

Figure 7. Peak Leakage Pressures Measured Out the Back of Test Structure Compared to Predicted Values in References 1 and 2

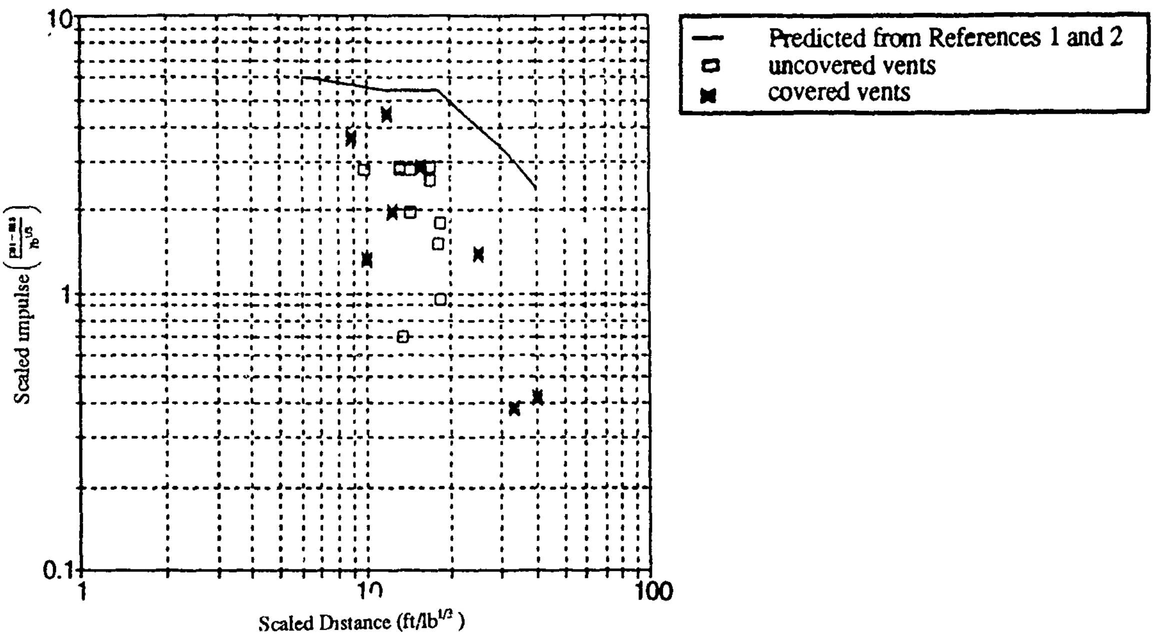

Figure 8. Scaled Leakage Impulse Measured Out the Back of Test Structure Compared to Predicted Values in References 1 and 2

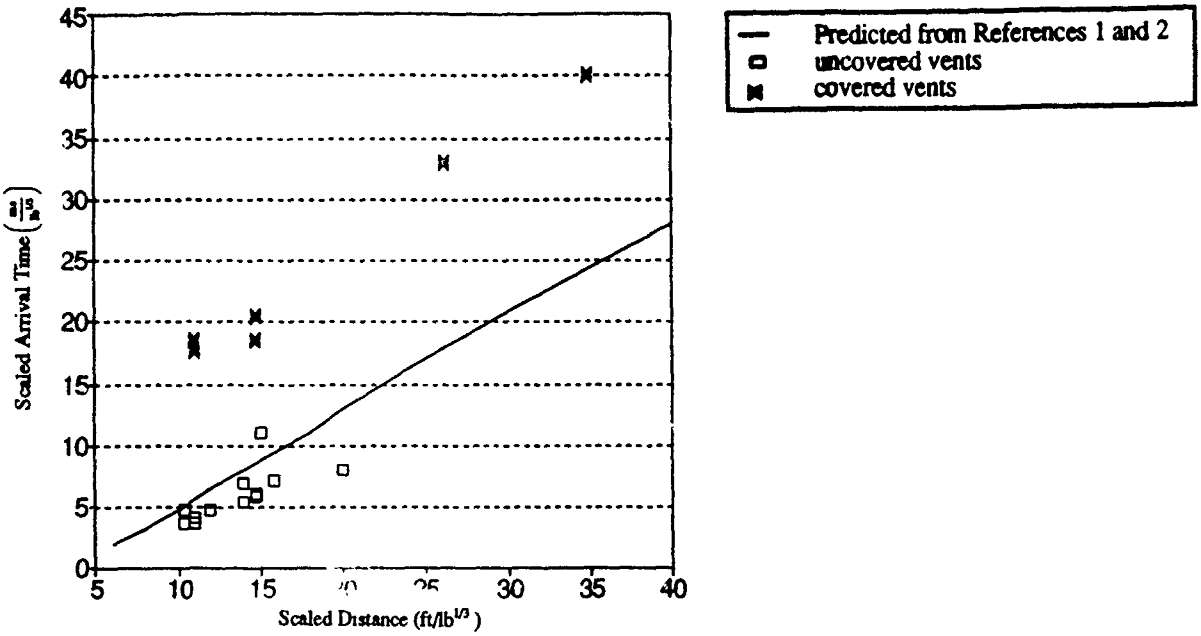

Figure 9. Scaled Arrival Time of Peak Leakage Pressure at Scaled Distances Out the Front of Test Structure

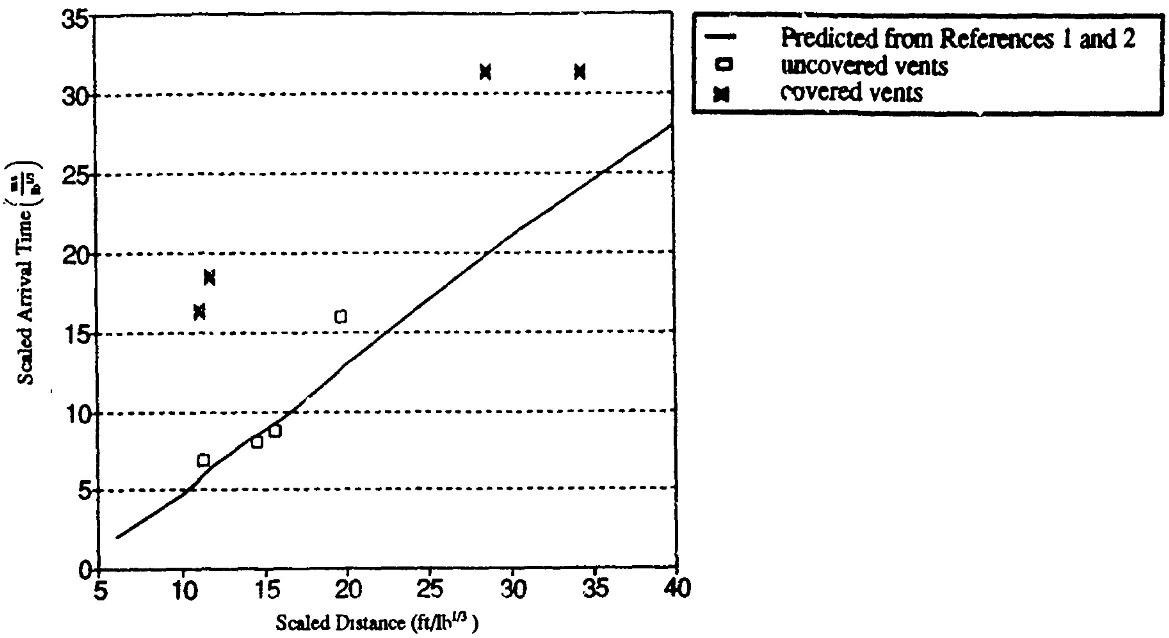

Figure 10. Scaled Arrival Time of Peak Leakage Pressure at Scaled Distances Out the Side of Test Structure

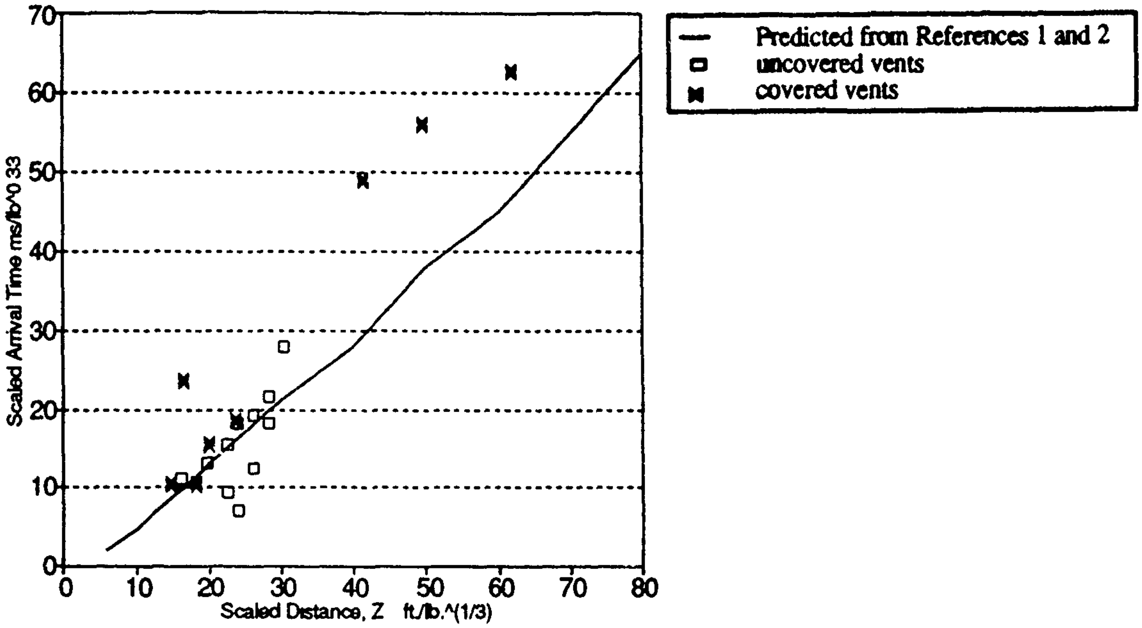

Figure 11. Scaled Arrival Time of Peak Leakage Pressure at Scaled Distances Out the Back of Test Structure

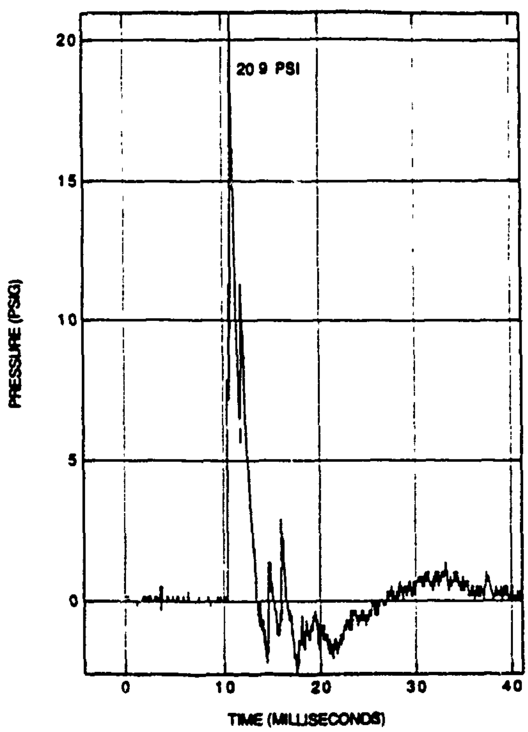

Figure 12. Typical Leakage Pressure History Measured Out the Front of Test Structure Through Uncovered Vent Opening

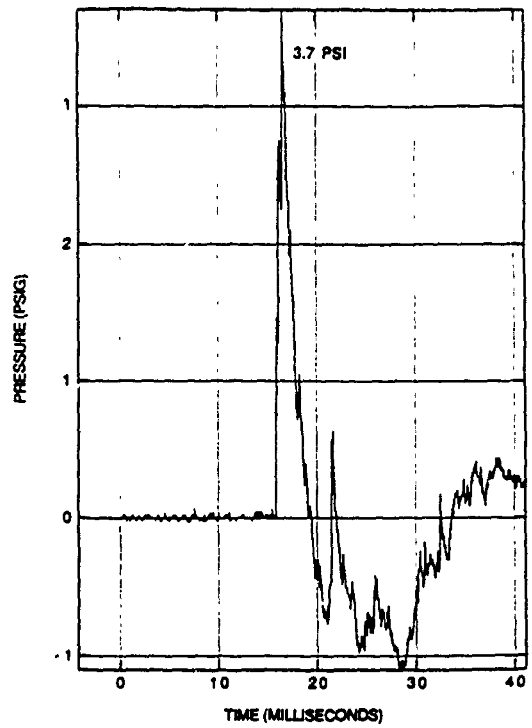

Figure 13. Typical Leakage Pressure History Measured Out the Side of Test Structure Through Uncovered Vent Opening

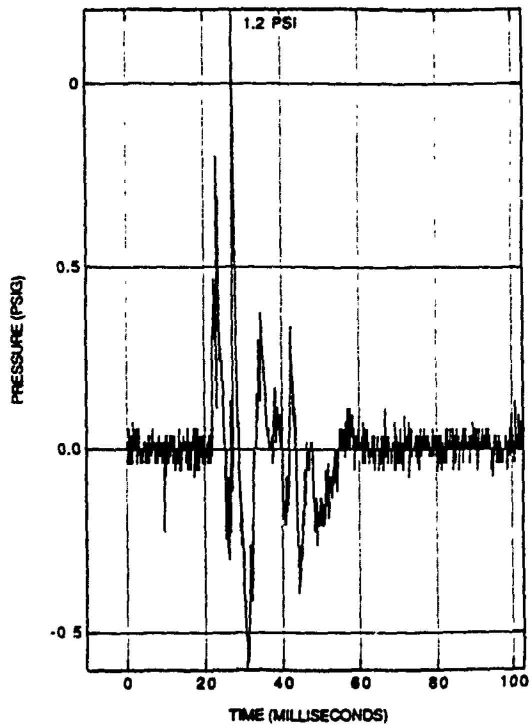

Figure 14. Typical Leakage Pressure Measured Out the Back of Test Structure Through Uncovered Vent Opening

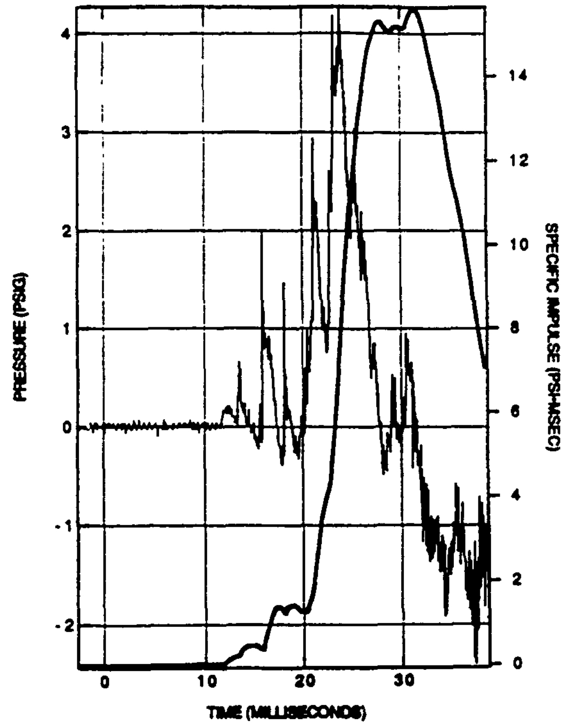

Figure 15. Typical Leakage Pressure History Measured Out the Front of Test Structure Through Covered Vent Opening

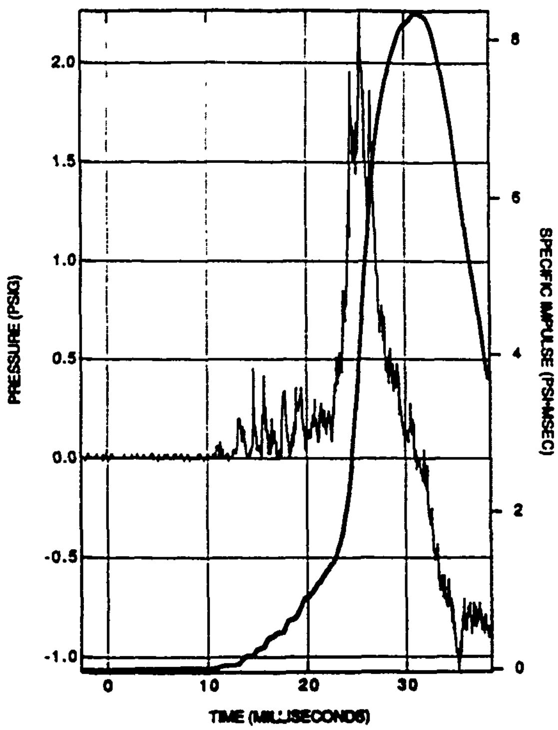

Figure 16. Typical Leakage Pressure History Measured Out the Side of Test Structure Through Covered Vent Opening

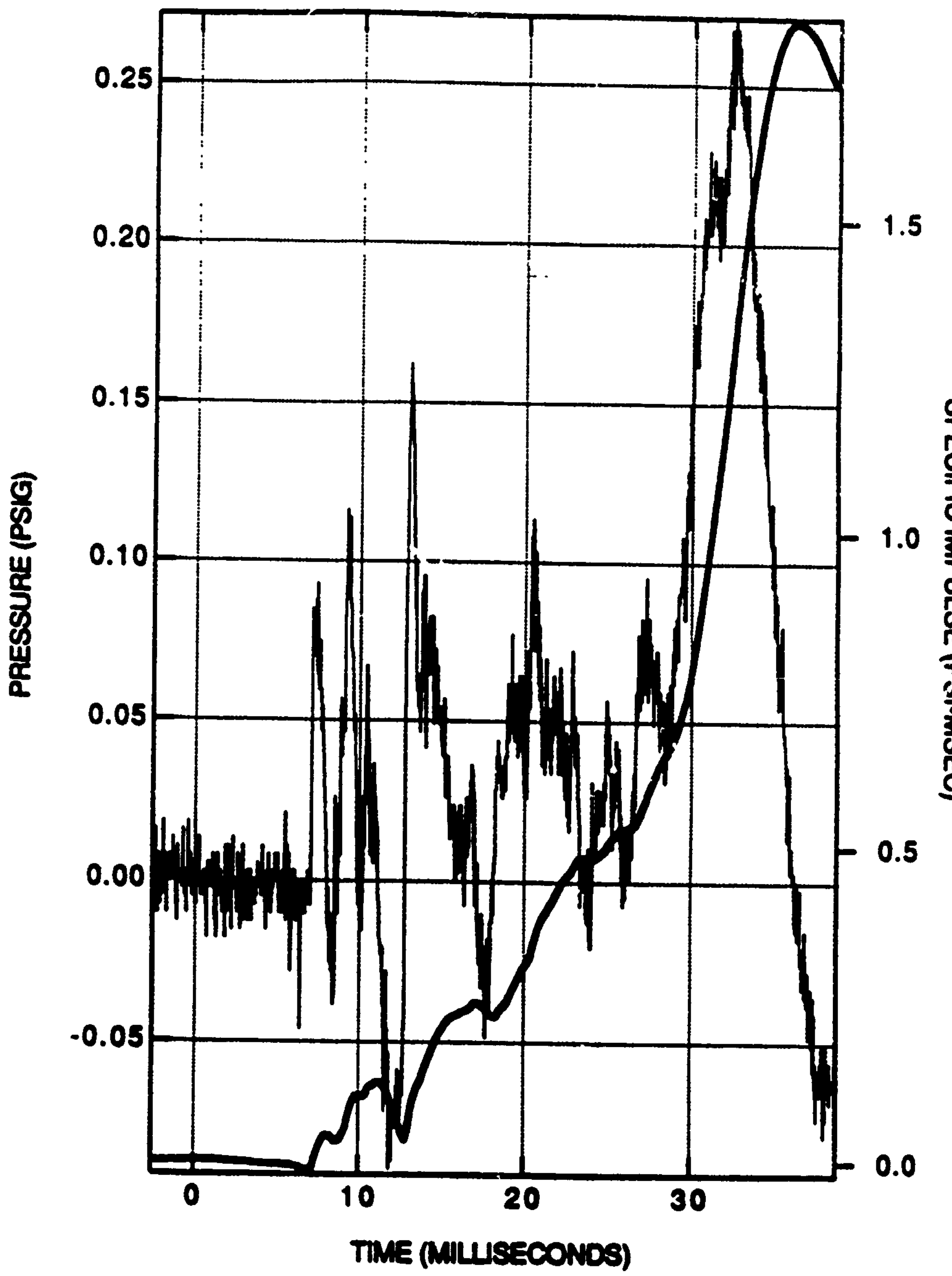

Figure 17. Typical Leakage Pressure History Measured Out the Back of Test Structure Through Covered Vent Opening

"AIRBLAST ATTENUATION AND FLOW LOSS PERFORMANCE OF PASSIVE ATTENUATORS"

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ABSTRACT

An analytical/experimental program was conducted for Waterways Experiment Station (WES) to develop a passive airblast attenuator to protect hardened shelters from conventional weapon attack. The role of a passive attenuator is to provide protection through attenuation of air shock, which would otherwise enter air ducts, damaging sensitive air filtration and decontamination equipment, electronic and mechanical systems, and injuring building occupants. The design constraints placed on the passive attenuator were that it have no moving parts, be inexpensive, and require no maintenance. Further, air flow loss under normal operating conditions was not to exceed 2.0 in.-H_2O at 500 ft/min. The goal was 99% attenuation of both pressure and impulse.

A Phase I analytical study evaluated the feasibility of using Suppressive Shields concepts for passive attenuators. A series of orifice plates was found to offer less resistance to normal air flow, yet equal or exceed the attenuation levels of any of the Suppressive Shields concepts. The Phase II experimental work included both airblast attenuation and flow loss measurements, and evaluated six concepts, three of which were orifice plate designs. The flow loss requirement proved to be very stringent, and measured losses were greater than analytical predictions. Airblast attenuation levels of 86 to 92% were measured with several orifice plate designs, but with 10 to 14 in.-H_2O pressure drop. Two orifice plate concepts achieved 80 to 85% attenuation of both pressure and impulse at the 2.4 in.-H_2O requirement.

Departing from orifice plate designs in an attempt to improve performance, three concepts were evaluated that directed the shock wave into holding chambers. The best of these designs achieved 87-95% attenuation, with a flow loss of 2.6 in.-H_2O at 500 ft/min.

BACKGROUND

The development of a passive airblast attenuation device for conventional weapons was promulgated by the U. S. Army Engineer Waterways Experiment Station (WES). Active blast valves, designed predominantly for long duration nuclear airblast, have closure times ranging from 1 to 2 ms (Refs. 1, 2). Tests run at WES revealed that such response times are too slow to effectively attenuate the blast from a conventional weapon (Refs. 3, 19). WES conducted full-scale tests using general purpose bombs. Active valves were blocked open during a number of tests, and their performance was compared to tests in which the valve was fully functional. Very little difference

was seen between the performance of active and blocked valves. Furthermore, some types of the active valves failed to operate properly under repeated high blast pressures from conventional weapons. These valves were found to be relatively fragile, deforming and seizing shut.

A passive airblast attenuation device that contains no moving parts is attractive because of its potential as a rugged, low cost, low maintenance item. Active valves may be the weak link in a facility under a multi-hit attack or at loads higher than design pressure. Further, the active valves must be cleaned to ensure that dirt, sand, or other particles do not interfere with the motion of a moving component, or prevent proper seating of the valve. The maintenance, reliability, and fragility problems associated with active valves are eliminated with a passive attenuator.

A Phase I study was completed in October of 1989 (Ref. 4). The concepts evaluated in Phase I were based on the Suppressive Shields program, which was active in the mid 1970's (Refs. 5-13). The Suppressive Shields program developed, analyzed, and tested a number of concepts for fixed, vented panels and structures. All vented panels were intended to strongly attenuate airblast from an internal detonation, and to arrest high speed fragments. The suppressive shields concepts were:

1. nested angles,
2. side-by-side angles or zees,
3. louvers,
4. interlocking I-beams, and
5. perforated plates.

A passive device consisting of a series of perforated plates was analyzed thoroughly. Shock tube data (Refs. 6, 15) were used to develop a design curve for peak pressure attenuation using a series of perforated plate with equal vent area per plate. A similar design curve was developed for impulse attenuation based on WES experiments (Ref. 18). The WES data showed impulse attenuation through perforated plates was generally not as great as pressure attenuation. It must be noted that it was assumed that single-plate data could be applied to a series of multiple plates, as recommended in References 9 and 10, but no test data existed during the Phase I study to verify this assumption. Phase II tests have subsequently proven this assumption to be false. The interaction of shock between plates reduces the effectiveness of the second and subsequent plates. As a result, the Phase I study overpredicted the attenuation of peak pressure.

The Phase I study analyzed flow loss through a perforated plate passive attenuator. A significant finding of this study was that flow loss through a plate with many perforations is significantly greater than that of a single orifice plate of equivalent vent area. Since shock tube tests show that pressure attenuation was independent of the perforation pattern as long as the holes were of larger diameter than plate thickness (Refs. 6, 14, 15), the Phase I study recommended a single orifice per plate, with the orifices offset to diagonally opposite corners of a square plate.

Nested angles, side-by-side angles or zees, louvers, and interlocking I-beams were also studied. Attenuation predictions were limited to peak pressure due to a lack of impulse attenuation concerning these devices. The Suppressive Shields data were the basis for peak pressure attenuation predictions in all cases (5-13). Flow loss calculations were also very limited due to the lack of empirical data for these geometries. However, it was readily apparent that flow losses through these devices would be higher than an orifice plate of equivalent vent area, and that attenuation through the perforated plates would be superior.

DESIGN CONSTRAINTS

The following are the design constraints imposed on the passive attenuator:

1. Pressure attenuation of 100:1 or greater
2. Impulse attenuation of 100:1 or greater
3. Air flow restriction of 2.0 in.-H_2O or less at 500 ft/min
4. No maintenance
5. Low cost
6. Applicable to new as well as existing facilities

Missing from the list of design constraints is delineation of the size of the duct to which a passive attenuator will be coupled. The approach taken was that all passive devices have the same cross-sectional area as the downstream duct. This approach prohibited use of a passive device that was larger than the mating duct's area, or use of multiple passive devices that are collectively larger than a duct, to meet the flow loss design constraint. The latter approach is commonly employed with active blast valves (Refs. 1, 2).

Requiring passive attenuator cross-sectional area to equal duct area is a very stringent constraint. But, the small size will be beneficial in the design of protective structures by minimizing the area of the exterior opening as well as the internal building volume occupied by the device.

Pressure Drop Test Apparatus

The pressure drop characteristics of air flowing through the passive attenuators was determined using a specially constructed wind tunnel. The design of the tunnel, illustrated in Figure 1, was based on the recommendations of ANSI/AMCA Standard 210-85 (ANSI/ASHRAE Standard 51-1985) *Laboratory Methods of Testing Fans for Rating*. The tunnel consists of three sections. The first was an 8-ft-long entrance section with a 2 x 2-ft cross-section. The blast valve model to be evaluated was positioned in this entrance section for testing. A flow straightening screen was located midway in the entrance section. This screen broke up any large scale turbulence caused by the flow through the blast valve. The entrance section opened into a central plenum chamber 8-ft long, with a cross-section of 4 x 4-feet. The chamber was divided in half by a central bulkhead that was penetrated by three ASME long radius flow nozzles, two each with 6-inch throat diameters, and one with a 5-inch throat. Upstream and downstream of the flow nozzles and bulkhead were flow straighteners consisting of 3/8-in. aluminum honeycomb and fine mesh wire screens. The central chamber was connected to a 4-ft long tail section with a 2 x 2-ft cross-section. A large centrifugal blower was connected to the end of the tail section to pull air through the tunnel. The blower was powered by a directly coupled 15 HP hydraulic motor. Blower speed and flow rate were controlled by a flow control valve on the hydraulic supply line to the motor.

Tunnel instrumentation included a magnetic pick-up, 60-tooth gear and frequency counter for measuring blower rpm; a thermocouple and digital display for measuring entrance section air temperature; and Magnehelic® gauges and an inclined 6-inch manometer for measuring differential pressures. The Magnehelic gauges were used for preliminary tests and rough pressure measurements, and the manometer used for final testing because of its superior accuracy and resolution. Flush-wall pressure taps were used to measure pressures upstream and downstream of the nozzle bulkhead. Pressures downstream of the test article in the entrance section were taken by a static probe extending into the flow and located behind the flow straightening screen in the entrance section.

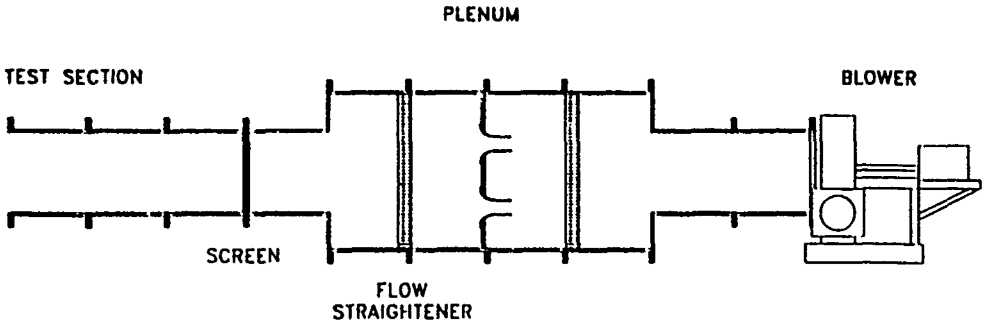

Figure 1. Schematic of Pressure Drop Test Apparatus

The data were analyzed following the recommended procedures and formulations in ANSI/AMCA Standard 210-85. An iterative procedure was used to calculate total flow through the wind tunnel using the combined throat areas of the ASME flow nozzles in use, barometric pressure, wet and dry bulb temperatures, and the pressure drop across the nozzles as inputs. Actual flow rates through the tunnel were calculated; then the average flow velocity using the cross-sectional area of the attenuator under test was determined. Finally, a least-squares second order curve was fit through the data, and produced a graph of the results in the form of air velocity versus pressure drop curves.

Airblast Attenuation Test Fixture

The test apparatus for airblast attenuation measurements was designed to evaluate performance of a passive device mounted flush in an external wall of a structure. The apparatus had three main components: a wall, a tunnel, and a passive device.

The wall consisted of a 6 X 5 X 2.5-ft reinforced concrete, steel clad block. The width and height of the wall's front face were designed to allow sufficient time for completion of the positive phase before rarefaction waves reached the passive attenuator.

The tunnel measured 28 ft long, and was fabricated from 12 X 12 X 1/4-in. square steel tube. It served several purposes. Its cross-sectional size was identical to that of all passive attenuators, thus eliminating expansion or compression of a shock exiting an attenuator. The length of the tunnel was selected based on shock-tube data which indicated that shock waves disturbed by an orifice plate will coalesce within a distance of seven tube diameters from the plate (Refs. 14, 15). An internal gage was conservatively placed 13 diameters downstream of the front face of the attenuator in the tunnel. The remaining 15 ft of tunnel downstream from the gage acted to delay the arrival of the external shock entering through the open end of the tunnel.

The wall and connected tunnel are shown in Figure 2. Each passive attenuator was designed to fit within the cavity depicted in the vertical cross-section shown in Figure 2. The center of the 12 x 12-in. attenuator opening was positioned level with the charge, 10 in. above ground level. Placement of the opening at this position was accomplished by burying the wall 14 in., as shown in Figure 2.

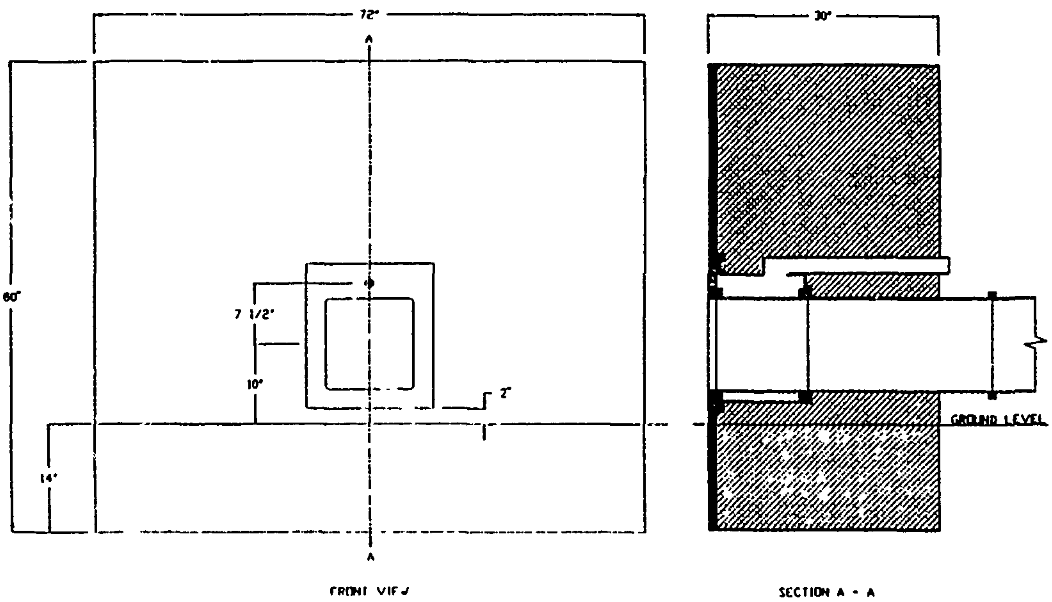

Figure 2. Airblast Attenuation Test Fixture

It was necessary to account for shock decay as the shock traveled down the tube. This was accomplished by baselining the tunnel without a passive attenuator installed. An empty housing of the same internal dimensions (11.5 X 11.5 in.) as the tunnel was substituted for a passive device during baseline tests. The ratio of tunnel pressure to incident pressure was calculated at each standoff. The same ratio was calculated for each passive device and divided by the baseline pressure ratio to determine pressure attenuation percentage. The formula developed was:

$$Pressure\,Attenuation = \left[1 - \frac{(P_T/P_1)_{attenuator}}{(P_T/P_1)_{baseline}}\right] \times 100$$

where P_1 is the reflected pressure at the external opening of the passive attenuator and P_T is the side-on pressure measured 13 ft downstream of the attenuator entrance. The formula calculates the attenuation directly attributable to the passive attenuator, with the effects of unrestricted opening size and tunnel length not being credited to the attenuator's performance. Impulse attenuation was calculated in a similar manner.

Two-pound, Composition B spherical charges were used in all tests. Two standoffs were selected for testing. Horizontal standoffs of 48 and 77 in. from the charge to the front face of the wall produced reflected pressures of 200 and 850 psi, respectively, at the openings of the test attenuators.

Reflected blast pressure on the front face of the attenuator was measured using 1,000 psi PCB Model 102A flush-mounted quartz pressure transducers. This transducer was mounted on the vertical centerline and 7 1/2-in. above the centerline of the attenuator.

Blast pressure downstream of the attenuator was measured with a PCB pencil gage mounted on the end of a 15-ft long, 3/4-in. PVC pipe inserted into the tunnel from the open end. The pipe and gage were supported by two sets of double-legged PVC braces. Both the pipe and bracing acted to isolate the gage from tunnel vibration. Pressure levels measured by the pencil gage varied with different attenuator configurations. A PCB 137A12 pencil gage was used when expected pressures were between 5 psi and 50 psi. A PCB 137M15 pencil gage was selected for expected pressures below 5 psi. The sensing element of the pencil gage was positioned 13 ft downstream of the front face of the passive devices.

Pressure signals were amplified using a PCB Model 483B07 amplifying power unit. A LeCroy 6810 digitizing system converted the data to digital form. The pressure data were sampled at a rate of one reading per microsecond. A total of 131,072 data points were recorded per channel per test, providing 0.131 second of data.

Baseline Airblast Attenuation

Baseline tests were conducted with 2-lb spherical charges at a 48-in. standoff to determine the charge height required to fully form a Mach stem at the height of the pressure transducer located directly above the opening to each passive attenuator. A fully formed Mach stem at the entrance to the attenuator was more desirable than multiple peak traces to avoid analysis of complicated pressure traces. A charge height above ground of 11 in. was found to be the upper limit. A 10-in. charge height was selected for testing.

Baseline tests were also conducted to provide reference data for evaluation of attenuator performance. Test results are shown in Table 1.

Table 1. Average Baseline Test Data

	Incident		13 Ft Down Tunnel			
Charge Standoff (in.)	P_r Reflected Pressure (psi)	i_r Reflected Impulse (psi-ms)	P_s Side-On Pressure (psi)	i_s Side-On Impulse (psi-ms)	P_s/P_r	i_s/i_r
48	782.1	91.11	22.78	33.28	0.293	0.3656
77	183.6	55.67	13.26	22.32	0.722	0.4033

Orifice Plate Passive Attenuators

The orifice plate design recommended as a result of the Phase I study (Ref. 4) is depicted in Figure 3. It consisted of six parallel orifice plates measuring 29.5 in. X 29.5 inches. The orifice in each plate had a radius of 4.25 in., which provided 6.25% vent area per plate. The orifices were offset to diagonally opposite corners from plate to plate.

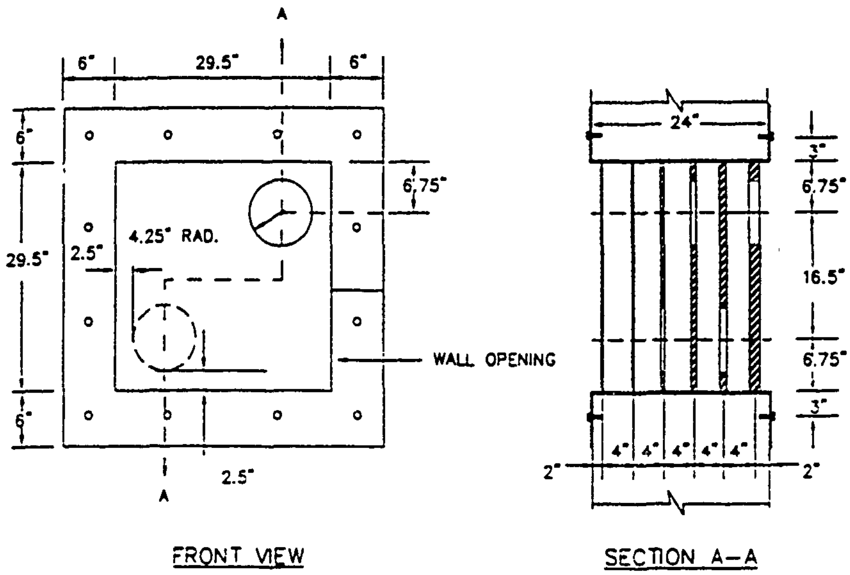

Figure 3. Six-Plate Orifice Device with 6.25% Vent Area

Pressure drop tests were conducted with the number of orifice plates being varied from a single plate to six plates. Plate positioning was as shown in Figure 3. The results of this series of tests are illustrated in Figure 4. This model demonstrated a high pressure drop at low flow velocities, with even the single plate with 6.25 percent open area exceeding 2.0 in.-H_2O of water pressure drop at just over 200 ft/min.

For the next series, the open area of each orifice plate was increased to 12 percent. In this series, only five plates were used, and the spacing between plates was adjusted in 1-in. increments between 2 in. and 8 inches. Figure 5 shows the results of this test series. The pressure drop with the larger open area was far superior to that at the 6.25 percent open area model, but still far short of the required level of performance. The results also show that plate spacings larger than 4 in. have negligible effect on pressure drop. Only as the plate spacing moves below four inches does performance begin to deteriorate. This is instructive since the cross-sectional flow area between plates at a 4-in. spacing is equivalent to a 17.8 percent open area for flow, far larger than the 12 percent open area of the orifice plates themselves. The deteriorating performance of the model as plate spacing was moved closer than 4 in. is attributed to the increasingly sharp turns the flow must negotiate.

Airblast attenuation tests involved a smaller version of the six-plate device described above, with the plates measuring 1 ft X 1 ft. Orifice size was 6.25%. The device was initially tested with only the first plate. Subsequent plates were added one at a time. Two repeat tests were conducted at 48- and 77-in. charge standoffs for each of the six configurations.

The results of airblast attenuation tests with 6.25% orifice plates are presented in Figures 6 and 7. These figures indicate that the addition of each plate improved attenuation, but the sixth

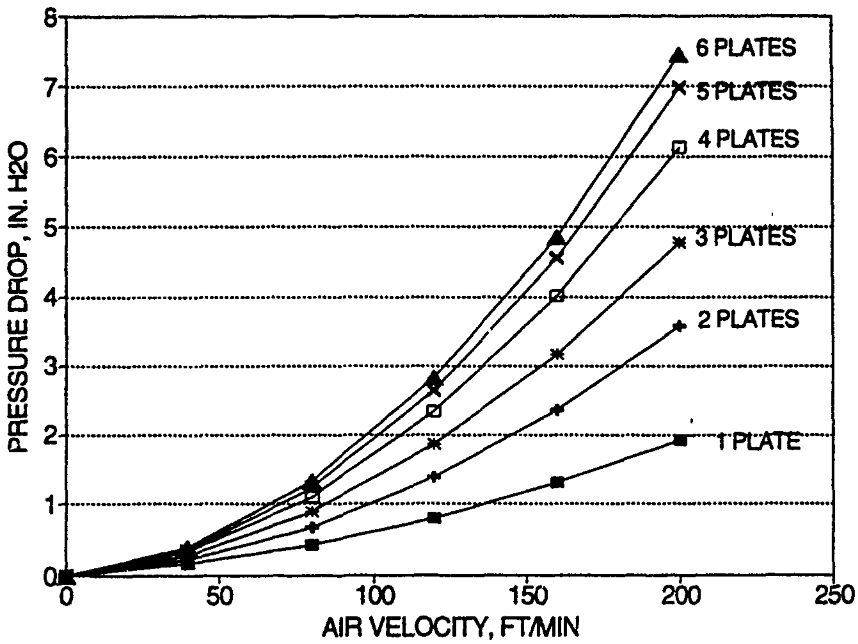

Figure 4. Pressure Drop Through Offset Circular Orifice Model, 6.25% Open Area, for Various Numbers of Plates, 4-In. Plate Spacing

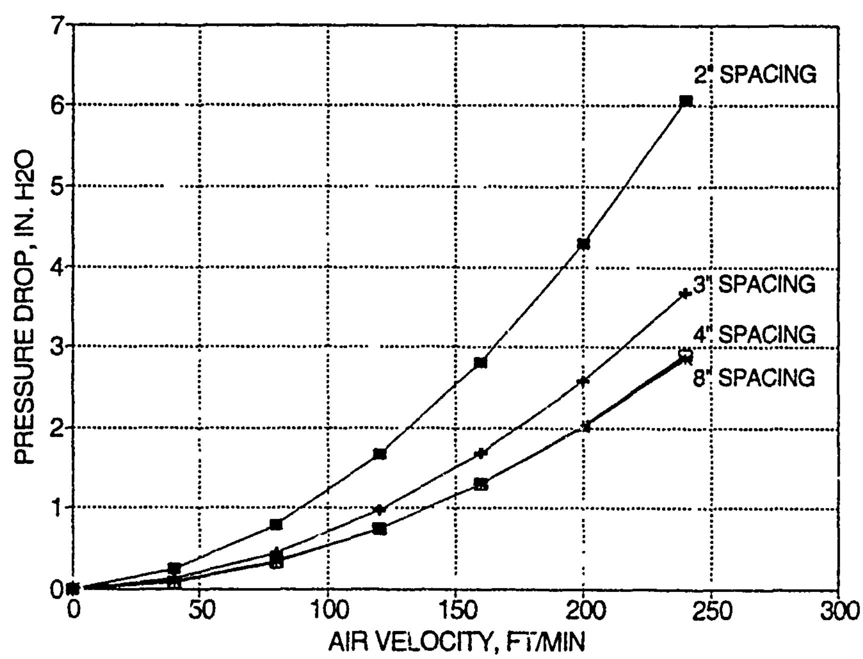

Figure 5. Pressure Drop Through Five-Plate Offset Circular Orifice Model, 12% Open Area, at Various Plate Spacings

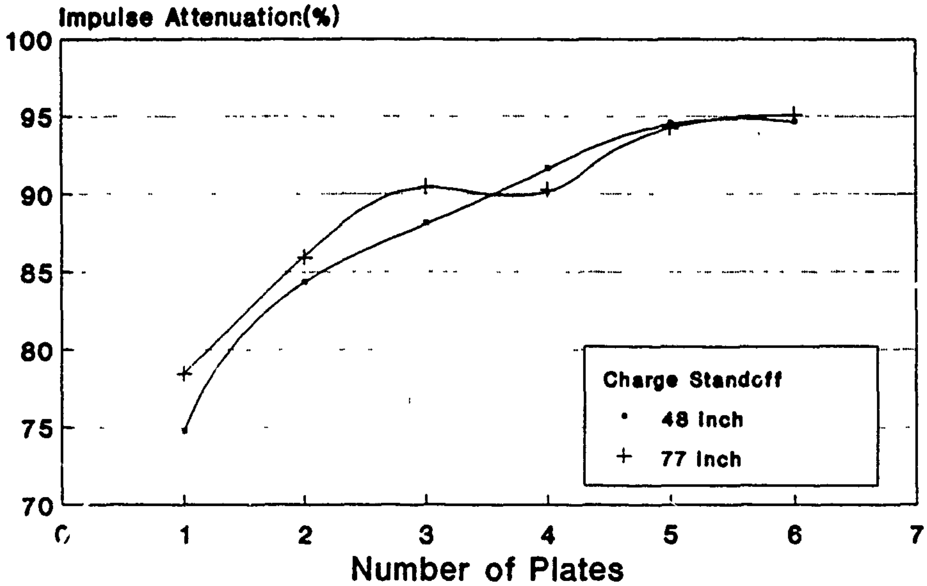

Figure 6. Impulse Attenuation Comparison of 6.25% Vent Area Orifice Plate Attenuator

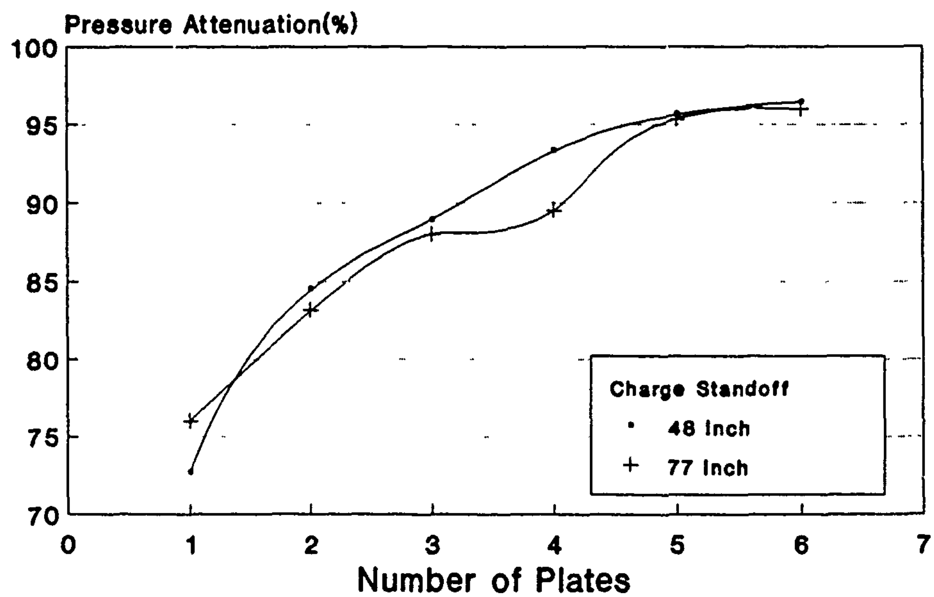

Figure 7. Pressure Attenuation of 6.25% Vent Area Orifice Plate Attenuator

plate made only a slight improvement. Attenuation performance with five plates was quite good, reaching essentially 95.5% pressure and 94.3% impulse attenuation at both charge standoffs. The sixth plate only marginally improved attenuation, the gains being less than 1 percentage point.

The sixth plate is of questionable value based on these results. A penalty is incurred in flow loss with the sixth plate, with very minimal attenuation improvement.

Pressure attenuation predictions made during Phase I for the second and subsequent plates greatly exceeded the measured performance. Clearly, the assumption that single-plate shock tube data could be used for multiple plates in succession was not valid for a six-plate, 6.25% vent area configuration.

The above tests revealed that larger orifice sizes and/or small numbers of plates would be required to meet the flow loss design constraint. The orifice size and number of plates were varied until it was ascertained that a four-plate, 31% vent area model would meet the flow requirement. This large vent area necessitated the use of rectangular orifices, offset from side-to-side as shown in Figure 8.

As before, the test series with 31% orifice plates consisted of test runs at various plate spacings, ranging from 5 to 9 inches. The results of this series are shown in Figure 9. Pressure drop measured at 500 ft/min was 2.7-in. H_2O with the 9-in. plate spacing.

Airblast attenuation test results for the 31%, four-plate device design are presented in Figures 10 and 11 as a function of plate spacing. The 4-in. plate spacing equates to a total depth for the device of 1 ft, which is the same overall depth of the 6.25%, six-plate configuration. Peak pressure attenuation for the 4-in. plate spacing was 82.9 and 81.1% at the 48- and 77-in. standoffs, respectively. The corresponding impulse attenuations were at 77.2 and 81.0%.

Increasing plate spacing of the 31%, four-plate configuration reduced attenuation, particularly impulse, which fell from 81.0 to 66.6% at the 48-in. charge standoff at plate spacings of 4 and 12 in., respectively, as shown in Figure 11.

It was concluded that orifice plate spacing should be at the minimum spacing that is acceptable from a flow loss standpoint. In general, this spacing will be about 1.5 times the orifice width for a rectangular orifice.

Device 3, shown in Figure 12, represented a departure from the Suppressive Shields or orifice plate concepts. Tests of orifice plate configurations revealed that large orifice sizes would be required to meet the flow loss design constraint, and that shock attenuation of 80 to 83% was the best that could be expected. Device 3, and later Devices 5 and 6, were developed to have improved flow characteristics and shock attenuation performance compared to orifice plates. These three devices no longer relied upon a series of restrictions to attenuate shocks. Rather, they directed shocks into holding chambers, which redirected the reflections toward the entrance.

Device 3 relies upon four chambers to accept and expand a blast wave, with reverse flow being directed at a shallow angle toward the front of the device. A blast wave enters through a 6.5% orifice in the front plate of Device 3. Each of the four chambers has a vane which directs approximately 2/3 of the blast wave into a chamber, with the balance passing through a 6.5% (of frontal area) passage. A rear orifice plate was positioned downstream of the four chambers, which also had a 6.5% orifice.

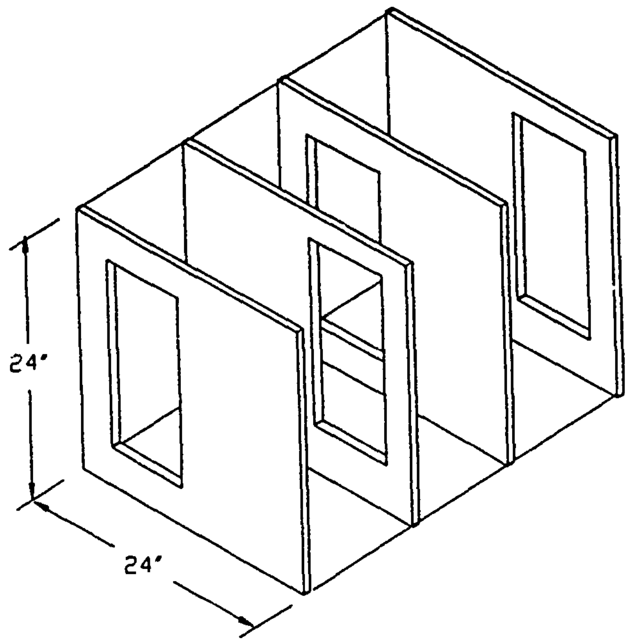

Figure 8. Configuration of Four-Plate Rectangular Orifice Model

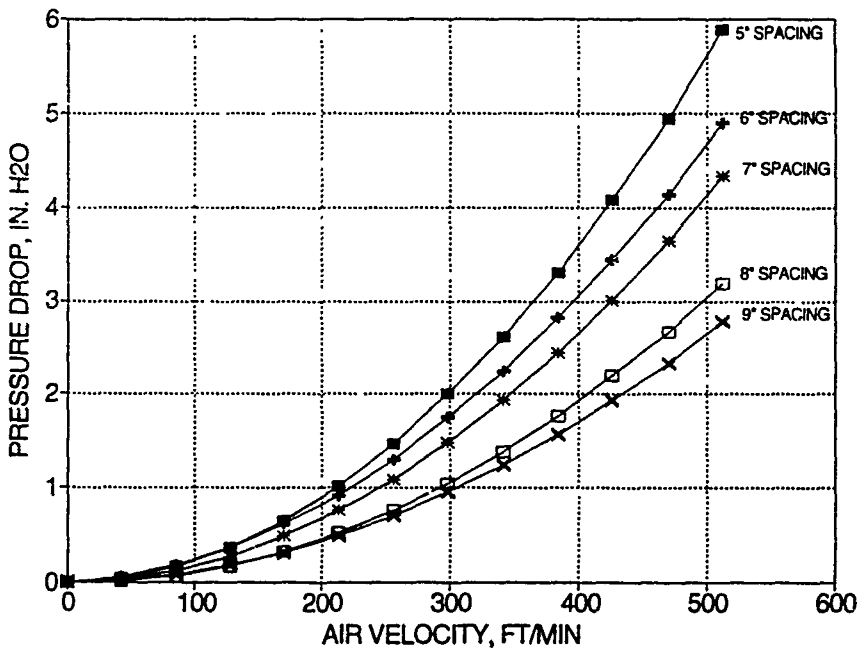

Figure 9. Pressure Drop Through 2 X 2-ft Four-Plate Rectangular Orifice Model, 31% Open Area, for Various Plate Spacings

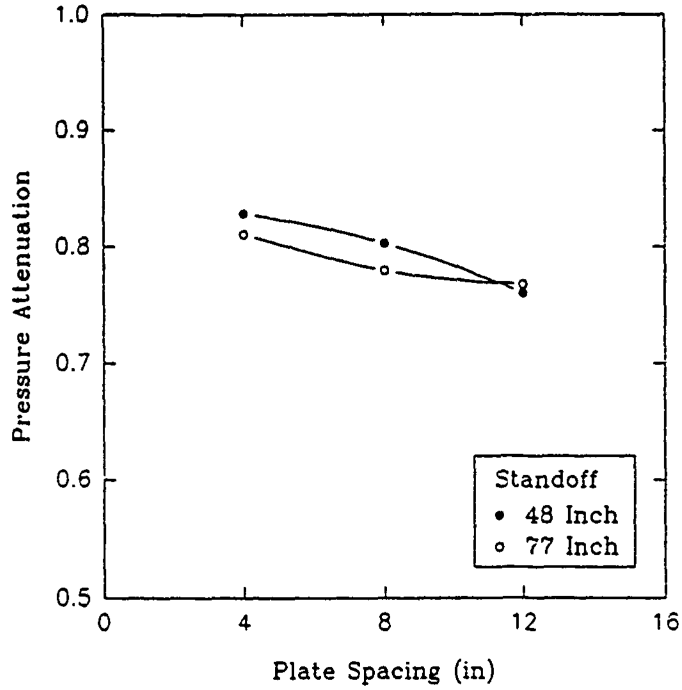

Figure 10. Effect of Plate Spacing on Pressure Attenuation; 31%, Four-Plate 1 X 1-ft Rectangular Orifice Model

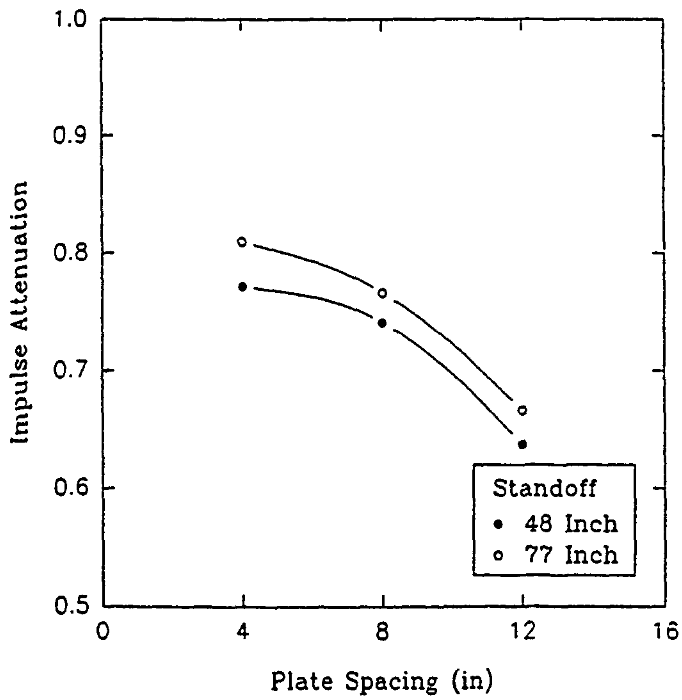

Figure 11. Effect of Plate Spacing on Impulse Attenuation; 31%, Four-Plate 1 X 1-ft Rectangular Orifice Model

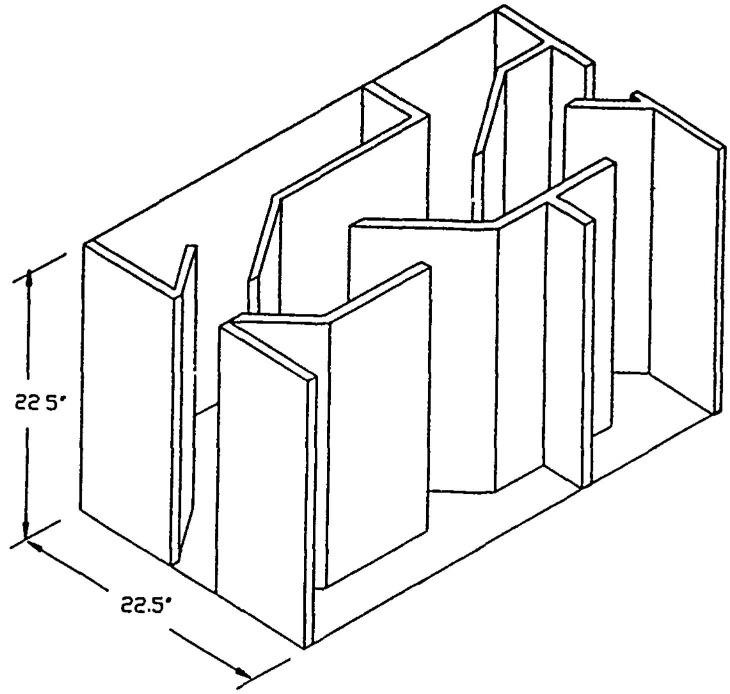

Figure 12. Configuration of Device 3 (Top and Right Walls Removed)

A 12% vent area version of Device 3 was also developed. This was accomplished by doubling the dimensions of the center vane assembly, which made it twice the width and length shown in Figure 12. The width and height of the housing were not increased; consequently, the wider vane assembly reduced the width of the chambers. This loss in chamber width was made up by increased chamber length, with the final chamber volumes being essentially the same as the 6.5% vent area model.

Flow loss tests were conducted on both the 6.5 and 12.0% Device 3 models, but only the 6.5% design was subjected to airblast attenuation tests. Airblast attenuation tests were not conducted with the 12% model when it was found that the more restrictive 6.5% model would not meet the 100:1 attenuation goal.

The results of the pressure drop tests are shown in Figure 13. Even though the 12 percent open area model performed significantly better than the 6 percent open area model, its performance was not as good as the 12%, six-plate orifice model (with plate spacings greater than 4 in.). This disappointing result is attributed to the internal turbulence and flow separation in the device as the flow passes around the internal baffle plates.

The results of airblast attenuation tests of Device 3, conducted with the 6.5% vent area design, are presented in Table 2. Shock attenuation was almost identical for the two charge standoffs (48 and 77 in.). Peak pressure and impulse were reduced by essentially 95 and 93%, respectively. These values are very close to those of the six-plate 6.25% orifice plate attenuator measured at the 77-in. charge standoff. Thus, Device 3 did not achieve the desired improvements over orifice plate designs.

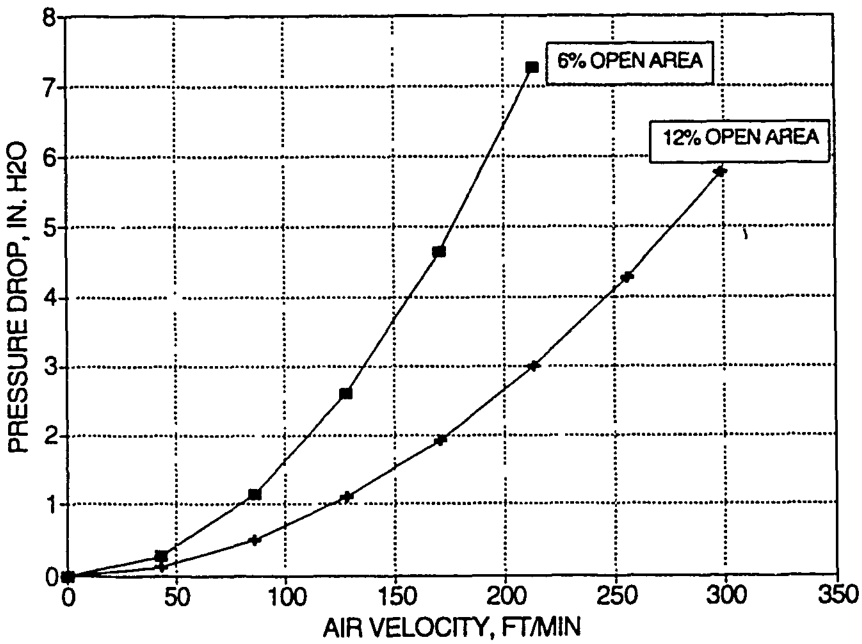

Figure 13. Pressure Drop Through Device 3 with 6% and 12% Open Areas

Table 2. Performance of 6.5% Vent Area Device No. 3

Shock Attenuation (%) 48-In. Standoff		Shock Attenuation (%) 77-In. Standoff	
Pressure	Impulse	Pressure	Impulse
96.3	93.7	95.2	94.0

Device 5, shown in Figure 14, consists of a series of angled plates, which, like Device 3, direct shocks to the sides and away from the opening to the next chamber. The shallow angle between plates reflects shocks toward the front of the device. The clearance between the tip of one plate and the side of adjacent plate controls flow area. Device 5 was subjected to flow loss tests first, where its design was optimized to meet the flow loss design constraint. Subsequently, the optimized design was subjected to airblast attenuation tests.

Two versions of Device 5 were flow loss tested: a 12% open area version, and a 31% open area version. The vent area through all restrictions was identical within these two models. As expected, the 31% open area model had significantly less pressure drop than the 12% open area model. Though sharing similarities with Device 3, Device 5 demonstrated much lower pressure drop, even with smaller open areas.

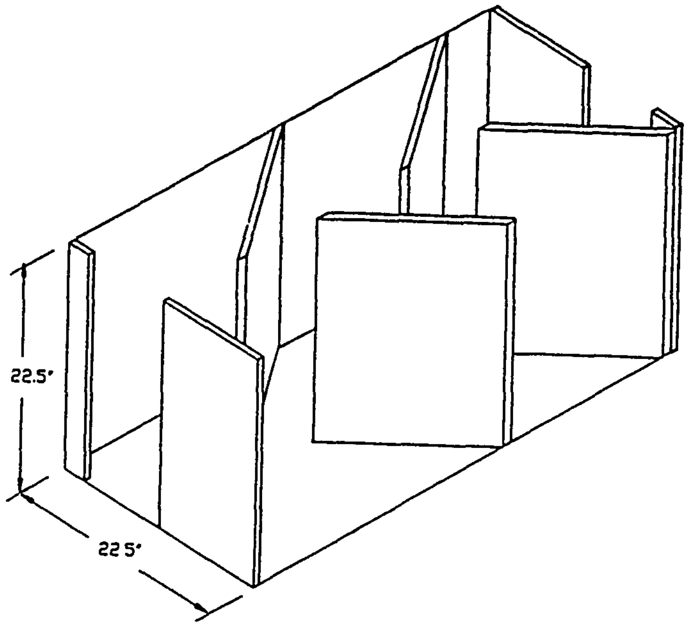

Figure 14. Configuration of Device 5
(Top and Right Walls Removed)

The 31% version of Device 5 was modified to include internal turning vanes to direct flow around the tip of each plate, as depicted in Figure 15. Figure 16 summarizes the results of the tests of the three versions of Device 5. The 31% open area model with turning vanes was very close to the performance standards established for the blast valve, with a pressure drop at 500 ft/min of 2.3 in.-H_2O.

The rear plate of Device 5 was removed, and the front opening width was varied to further reduce flow loss. It was determined that a 17.8% vent in the front plate, 31% open area at the tip of each internal plate, and no rear orifice plate would exactly meet the 2.0 in.-H_2O at 500 ft/min requirement. This configuration was subjected to airblast attenuation tests.

The results of airblast attenuation tests are presented in Table 3. The 77-in. standoff produced the best performance, with pressure being attenuated by 83.6% and impulse by 80.9%. These figures are essentially the same as the 31% four-plate orifice device. The turning vanes, necessary to achieve good air flow characteristics, could be the reason for the attenuation shortcomings.

The design of Device 6, shown in Figure 17, was formulated based on the cumulative knowledge from the previous attenuators. Device 6 relies upon a single chamber or "shock trap" to accept the incident shock and redirect it out the front opening. Tests with Device 3 identified the need for such a large chamber. Minimization of flow losses was paramount in the design of Device 6, which presents only three restrictions to normal air flow. The internal chamber was initially given a crude airfoil shape to minimize turbulence, but no attempt was made to improve this shape due to funding and time constraints.

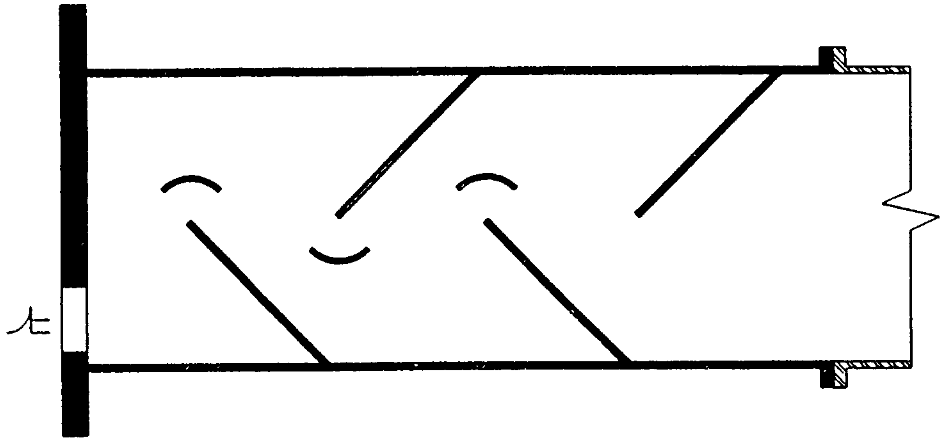

Figure 15. Device 5 with Turning Vanes

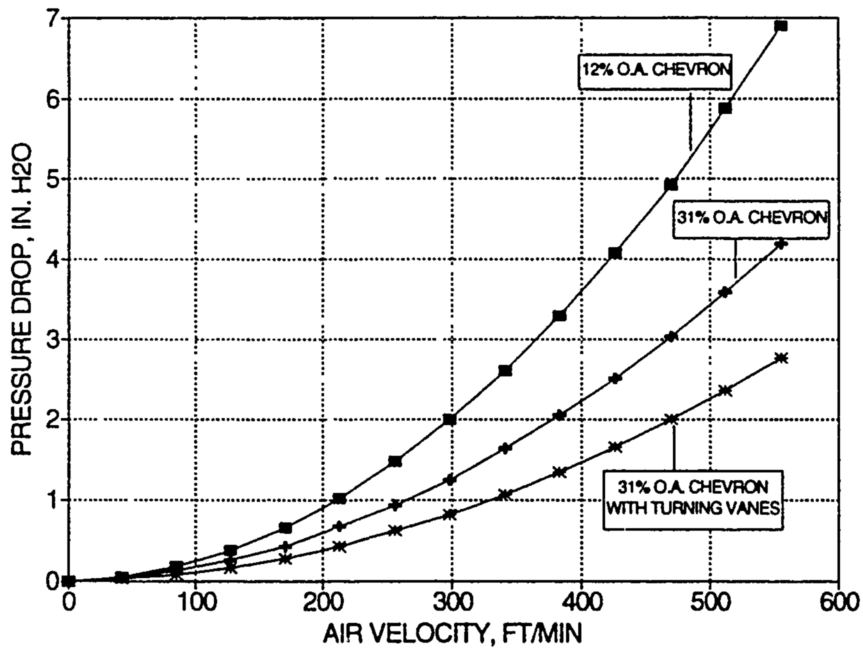

Figure 16. Pressure Drop Through Device 5; 12% Open Area, 31% Open Area, and 31% Open Area with Turning Vanes

Table 3. Airblast Attenuation of Device 5, tne Chevron Model

Front Plate Vent Area (%)	Internal Plate Vent Area (%)	Shock Attenuation (%) 48-In. Standoff		Shock Attenuation (%) 77-In. Standoff	
		Pressure	Impulse	Pressure	Impulse
17.8	31.0	81.2	77.1	83.6	80.9

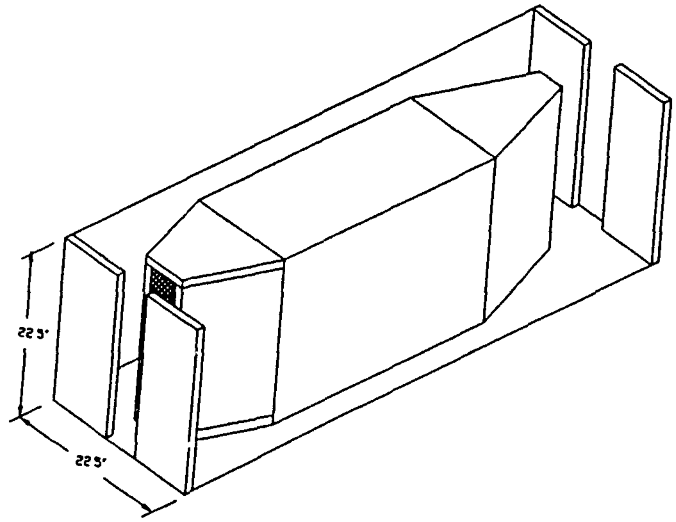

Figure 17. Configuration of Device 6 (Top and Right Walls Removed)

Device 6 was optimized for flow performance before attempting airblast attenuation tests. Airblast attenuation tests were then conducted, with modifications being limited to those items which did not affect flow loss performance.

Several flow loss test series were conducted on this model to determine optimum settings for standoff of the internal chamber behind the front plate, front plate opening width, and shock trap opening width. The ratio between front plate opening and shock trap opening was important to ensure that most of a shock wave passing through the front plate would enter the shock trap.

The final configuration had a 15.6 percent open area front plate, a standoff distance of 1.5 in. (for a 22.5 X 22.5 in. frontal area), an internal chamber mouth area of 22.2 percent., and a 22.2 percent rear orifice plate. The standoff distance provided a combined 13.3% vent area past the nose of the internal chamber. This final configuration had a measured pressure drop of 2.6 in.-H_2O at 500 ft/min, as shown in Figure 18. It is felt that the 2.0 in.-H_2O specification can easily be reached with further work to optimize the shape of the shock trap chamber to enhance smooth flow through the device.

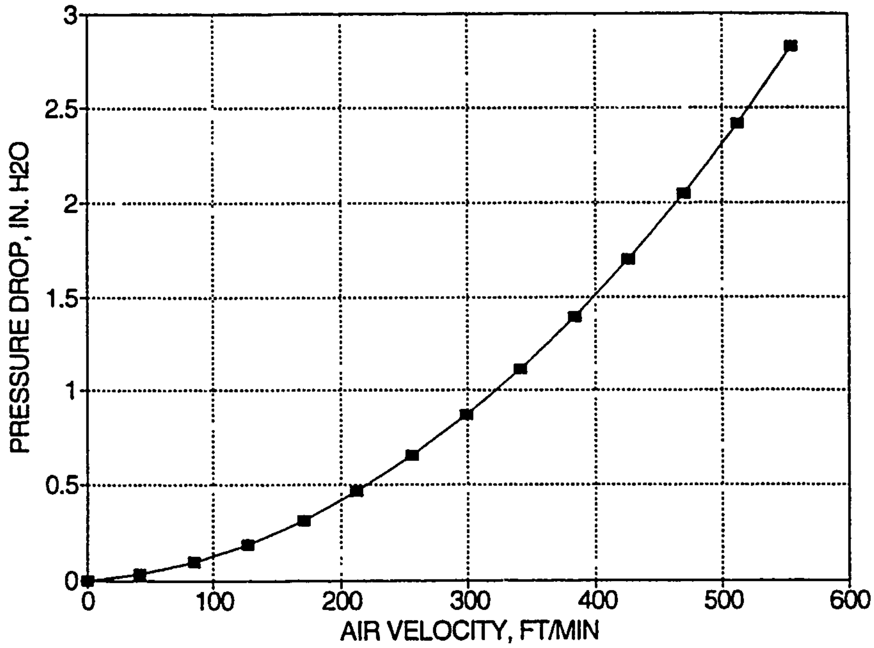

Figure 18. Pressure Drop Through Shock Trap Model, 15.6% Front Plate, 22.2% Shock Trap, 1.5-In. Standoff Distance, and 22.2% Rear Plate

An important observation made during flow loss tests was that flow stagnated across the mouth of the internal chamber. As a result, the internal configuration of the chamber has no effect on flow performance. This is a very important feature since it provides the freedom to develop a shock trap independent of air flow considerations. The following airblast attenuation tests evaluated several internal chamber designs.

A shock trap containing a converging nozzle as shown in Figure 19 was evaluated first. The results are shown in Table 4. Attenuation levels were 1 to 8 percentage points higher than any previously tested attenuator. The converging nozzle very effectively attenuated the shock reflecting out of the chamber, but this benefit was outweighed by a side-to-side reflection in the throat of the nozzle, which contributed to the initial shock that diffracted past the nose of the chamber.

The nozzle was removed from the internal chamber, resulting in an improvement in pressure and impulse attenuation at 77 in. of 2.3 and 1.3 percentage points, respectively, as shown in Table 4. The results at the 48-in. standoff were mixed, with a 0.6 point improvement in pressure attenuation, but a 0.9-point reduction in impulse attenuation.

The shock characteristics internally and downstream of Device 6 changed dramatically after removing the converging nozzle. Now, the first reflection out of the internal chamber dominated rather than the initial shock that diffracted past the nose of the chamber. It was evident that major improvements in Device 6 performance could be achieved if a means could be found to reduce the first reflection out of the internal chamber. To demonstrate the potential improvements, steel wool was loosely packed in the tail section of the internal chamber, occupying approximately

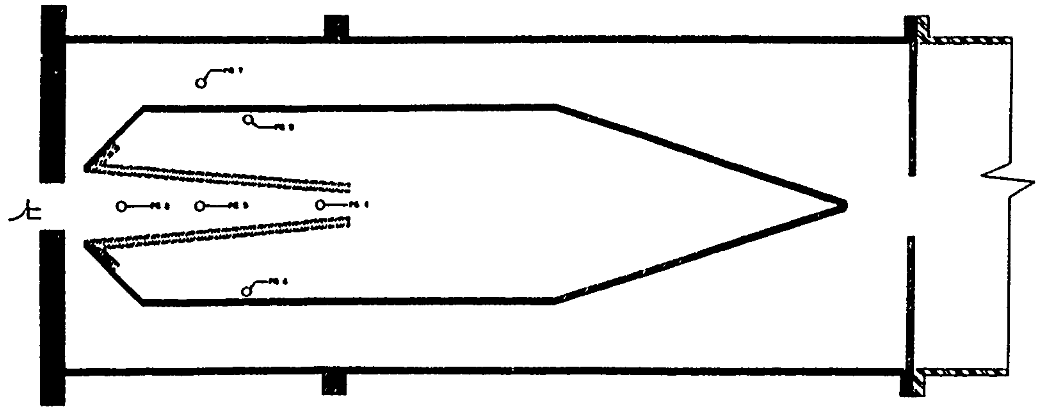

Figure 19. Device 6 Shown with Lengthened Internal Chamber

Table 4. Device 6 Shock Attenuation Test Results Using Long Internal Chamber

Internal Chamber Configuration	Shock Attenuation (%) 48-in. Standoff		Shock Attenuation (%) 77-in. Standoff	
	Pressure	Impulse	Pressure	Impulse
Converging Nozzle	83.9	85.5	86.2	88.8
Basic Design	84.5	84.6	88.5	90.1
Steel Wool in Rear 1/4	92.1	86.9	94.8	93.8

1/4 of the chamber volume. A piece of expanded metal was placed just ahead of the steel wool to keep the steel wool in place. The test results are shown in Table 4. Major improvements in attenuation were recorded. Attenuations at the 77-in. standoff were 94.8 and 93.8 percent for pressure and impulse, respectively. The numbers were not quite as high at the 48-in. standoff, with 92.1 and 86.9 percent pressure and impulse attenuation, respectively.

The first reflection from the internal chamber still dominated the downstream pressure records. This is especially true at the 48-in. charge standoff. Improvements in performance can easily be achieved through modification of the internal design of the chamber, and that attenuation levels of 96 to 97 percent are entirely feasible. Optimization of the design for flow performance will permit further reductions in opening sizes, with commensurate improvements in attenuation.

CONCLUSIONS

The feasibility of a low-cost, low-maintenance passive device was demonstrated through measurement of flow loss and airblast attenuation. Additional cost benefits will be realized in the design and construction of semi-hardened and hardened protective structures as a result of the small size of the passive devices, which have a cross-sectional area equal that of the ducting to which they are connected.

Orifice plates are the simplest passive device configuration, and this simplicity makes them inexpensive to fabricate from readily available materials. But, flow losses force the use of large orifices and dictate the plate spacing be greater than or equal to orifice width. Airblast attenuation is inversely proportional to plate spacing, so the smallest plate spacing that is acceptable from a flow loss standpoint should be used. Plate spacing was identified as a critical parameter concerning the airblast attenuation of orifice plate devices, but insufficient data were available to develop a correlation.

Two devices were designed with multiple side chambers into which shocks were directed. These devices equaled the performance of orifice plate attenuators with equal numbers of restrictions and vent areas. However, these designs were more complex, and since they did not represent a performance improvement over orifice plate designs, their added fabrication costs are not justified.

A passive device with a single chamber positioned closely behind the entrance to an attenuator proved to be very effective to accept and mitigate the preponderance of a shock wave. A design consisting of front and rear orifice plates and an elongated internal chamber achieved 92 to 95% pressure attenuation, and 87 to 94% impulse attenuation.

ACKNOWLEDGMENTS

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REFERENCES

1. "PV-Blast Valves," Temet USA Inc., Blast Valve Catalogs, "TUSA PV-200-86-4 and TUSA PV-120-300-86-0.

2. "Luwa Shelter Technology," Luwa Ltd., 1989.

3. James W. Ball, J. H. Weatherly, and S. A. Kiger, "Blast Valve Effectiveness for Conventional Weapons," Waterways Experiment Station, Miscellaneous paper No. SL-92-1, February 1992.

4. Q. A. Baker, C. Y. Tuan, and W. E. Baker, "Passive Airblast Attenuation Valves for Conventional Weapons," Waterways Experiment Station Contract No. DACA39-89-C-0035, WBE Report No. WBE-124, October 31, 1989.

5. "Suppressive Shields Structural Design and Analysis Handbook," HNDM-1110-1-2, U.S. Army Corps of Engineers, Huntsville Division, Huntsville, Alabama, November 1977.

6. C. Kingery, G. Coulter, and R. Pearson, "Venting of Pressure Through Perforated Plates, Technical Report ARBRL-TR-02105, Ballistic Research Labs, Aberdeen Proving Ground, Maryland, June 1977.

7. W. E. Baker and G. A. Oldham, "Estimates of Blowdown of Quasi-Static Pressures in Vented Chambers," EM-CR-76029, Report No. 2, Edgewood Arsenal, Maryland, November 1975.

8. J. F. Proctor, "Blast Suppression/Predictive Model, WBE 4333," Monthly Technical Report, Naval Surface Weapons Center, White Oak, Silver Spring, Maryland, November 1975.

9. W. E. Baker and P. S. Westine, "Methods of Predicting Blast Loads Inside and Outside Suppressive Structures," EM-CR-76026, Report No. 5, Edgewood Arsenal, Maryland, December 1975.

10. E. D. Esparza, W. E. Baker, and G. A. Oldham, "Blast Pressures Inside and Outside Suppressive Structures," EM-CR-76042, Report No. 8, Edgewood Arsenal, Maryland, December 1975.

11. R. N. Schumacher, C. N. Kingery, and W. O. Ewing, Jr., "Airblast and Structural Response Testing of a 1/4 Scale Category I Suppressive Shield," BRL Memorandum Report No. 2623, USA Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, May 1976.

12. A. Celmins, "Analysis of Category I Suppressive Shield Effectivity Data," BRL Report No. 1936, USA Ballistic Research Labs, Aberdeen Proving Ground, Maryland, September 1976.

13. R. N. Schumacher, "Airblast and Structural Response Testing of a Prototype Category III Suppressive Shield," BRL Memorandum Report No. 2701, USA Ballistic Research Labs, Aberdeen Proving Ground, Maryland, November 1976.

14. C. N. Kingery and G. Coulter, "Shockwave Attenuation by Single Perforated Plates," BRL Memorandum Report No. 2664, USA Ballistic Research Labs, Aberdeen Proving Ground, Maryland, August 1976.

15. C. Kingery, R. Pearson, and G. Coulter, "Shock Wave Attenuation by Perforated Plates with Various Hole Sizes," BRL Memorandum Report No. 2757, USA Ballistic Research labs, Aberdeen Proving Ground, Maryland, June 1977.

16. F. H. Oertel, Jr., "Evaluation of Simple Models for the Attenuation of Shock Waves by Vented Plates," BRL Report No. 1906, USA Ballistic Research Labs, Aberdeen Proving Ground, Maryland, August 1976.

17. J. D. Renick, K. L. Kloepple, and R. W. Robey, "Evaluation of Passive Blast Attenuation Devices," Phillips Laboratory, Report No. PL-TR-91-1052, October 1991.

18. J. R. Britt and C. D. Little, Jr., "Airblast Attenuation in Entranceways and Other Typical Components of Structures. Small-Scale Tests Data Report 1," WES/TR/SL-84-22, U.S. Army Waterways Experiment Station, Mississippi, December 1984.

19. D. W. Hyde, "NATO Semi-Hardened Facility Test," Technical Report ESL-TR-89-06, U.S. Air Force Engineering and Services Center, Tyndall AFB, FL, June 1989.

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MR.	BELL	KENNETH	NEW MEXICO ENGINEERING RESEARCH LAB
MR.	BELLING	DAN	NATIONAL TECHNICAL SYSTEMS

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MS.	BERRY	SHARON	NAVAL AIR WARFARE CENTER
ICA	BESSON	JACUES	Inspection de l'Armenent pour les
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MR.	BIENZ	ANDREAS	BIENZ, KUMMER & PARTNER LTD
MR.	BILLINGSLEY	LARON	THIOKOL CORPORATION
MR.	BISCOTTE	MICHAEL	HAYES, SEAY, MATTERN & MATTERN, INC.
MS.	BISHOP	NANCY	EXPLOSIVES SAFETY TEAM (ARMAMENT DIV)
MR.	BISHOP	STEPHEN	USBI, P&W, UTC
MR.	BISHOP	DAVID	62 AIRLIFT WING
MR.	BLAIR	DOUGLAS	HQ, USAREUR/7A
MR.	BLAYLOCK	NEIL	SOUTHWEST RESEARCH INSTITUTE
MR.	BLOOM	THOMAS	QUANTIC INDUSTRIES, INC.
MR.	BLOSE	THOMAS	NAWCWPNS
MR	BOAZ	GROSMAN	
MR.	BOBIS	JOHN	AEROJET PROPULSION DIVISION
LTC	BOCHAN	DOV	ASSISTANT MILITARY ATTACHE
MR.	BOHIS	JOHN	AEROJET PROPULSION DIVISION
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MR.	BOWEN	RICHARD	NAVAL SEA SYSTEM COMMAND
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SGT	BRINDLEY	PATRICK	EOD MALS-13
MR.	BRODERICK	CHARLES	LAWRENCE LIVERMORE NATIONAL LABORATORY
MR.	BROOKS	JESSIE	KAO
MR.	BROWER	JAMES	US ARMY TECH ESCORT-UNIT

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MR.	BROWN	NICHOLAS	PUEBLO DEPOT ACTIVITY
MR.	BROWN	MICHAEL	NAVAL SURFACE WARFARE CENTER
MR.	BROWN	LARRY	DENVER RESEARCH INSTITUTE
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MR.	BRUNTY	JOE	FEDERAL/OSHA
SMSGT	BRYANT	JAMES	102ND FW/SE
MR	BUEHLER	KURT	6510 TW/DORH
MR.	BUMMER	GLENN	CALIFORNIA INSTITUTE OF TECHNOLOGY
MR.	BURCH	V.	NAVAL SURFACE WARFARE CENTER
M/SGT	BURCHETT	STEPHEN	2701 EXPLOSIVES ORD SQUADRON
MR.	BUTLER	FENOY	GEO-CENTERS, INC.
MR.	BUTLER		US ARMY YUMA PROVING GROUND
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CAPTAIN	CARTER	JOHN	11 AF/SEW
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MR.	CENTENNIAL	CARL	SOUTHWEST RESEARCH INSTITUTE
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MSGT	CHARON	ROBERT	388 FIGHTER WING
MR.	CHASE	RONALD	542D CPTS/FMFP
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MR.	CHING	REGINALD	OLAC PHILLIPS LABORATORY
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MS.	CINNAMON	CYNTHIA	DEFENSE CONTRACT MGMT DISTRICT WEST
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MR	CLOONAN	JAMES	SM-ALC/SEW
MR.	COBB	WILLIAM	436 AW/SEW
MR.	COLBERG	MELVIN	U.S. ARMY DEFENSE AMMUNITION CENTER
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MR.	COLLIS	DAVID	NEW MEXICO INSTITUTE OF MINING
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MR.	CONNOR	JOHN	CHIEF OF SAFETY
MR.	CONSTANTINO	LARRY	PACIFIC SCIENTIFIC
MR.	COONFARE	GREGORY	445 AW/SEG
MR.	COULSON	JOHN	COULSON CONSULTING CORPORATION
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MSGT	DEUTSCH	KENT	EOD MALS-16 MAG-16 3RD MAW
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MR.	DOOLITTLE	CRAIG	NAVAL SURFACE WARFARE CENTER
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MR.	HUDSON	MELVIN	NAVAL SURFACE WARFARE CENTER
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MR.	MANNSHRECK	WILLIAM	NAVAL SAFETY CENTER
MR	MANTHEY	J.	US ARMY CORPS OF ENGINEERS
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SMSGT	MARSH	JOHN	3246 EQUIPMENT MAINTENANCE SQUADRON
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MR.	MCCORMICK	BILL	LOS ALAMOS NATIONAL LABORATORY
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MR.	MCQUEEN	JERRY	MOTOROLA INC.
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DR	MERRIFIELD	R.	TECHNOLGY DIVISION
MR	MERRILL	CLAUDE	OL-AC PL/RKCP
LTCOL	MEYER	WALLACE	825 BRENTWOOD PLACE
MR	MEYERS	GERALD	US DEPARTMENT OF ENERGY
MR.	MIKASA	GLENN	NAVAL WEAPONS STATION
MR.	MIKOLEIT	KURT	NAVAL SURFACE WARFARE CENTER
MR.	MIKULA	JAMES	U.S. ARMY ARDEC
MR.	MILLER	STEVE	UINIVERSAL PROPULSION CO.& INC
MR.	MILLER	STEPHEN	UNIVERSAL PROPULSION COMPANY, INC.
MR.	MILLER	PAUL	ALLIANT TECHSYSTEMS
CAPTAIN	MITTELMAN	GREG	AFMC, NUCLEAR SUPPORT OFFICE
MR.	MIXTER	HENRY	E.O.D. WORLD SERVICES, INC.
CAPTAIN	MONTANA	SCOTT	351 MW/SEP
MR.	MONTANARO	PAUL	NAVAL SURFACE WARFARE CENTER
MR.	MONTELEONE	PAUL	USARDEC
MS.	MONTROSS	JAN	SAFETY ENGINEERING
COMMANDER	MOODY	DEWITT	
MR.	MOOI	KOK HEONG	LANDS AND ESTATES ORGANIZATION
MR.	MOONEY	R.	TALLEY DEFENSE SYSTEMS, INC.
MR.	MOORE	HAROLD	TECHNICAL ANALYSIS, INC
MR.	MORAN	EDWARD	DDESB
MR.	MORCOS	MICHAEL	NAWC-WEAPONS
DR.	MORETON	P.	SRD
MR.	MORGAN	CHARLES	NAVAL UNDERSEA WARFARE
LTC	MORLEY	ALAN	UK ORDNANCE BOARD
MR.	MORRIS	TODD	U.S. ARMY SYSTEMS TEST FACILITY
MR.	MOXLEY	ROBERT	SAN ANTONIO AIR LOGISTICS CENTER/SEW
1LT	MUHL	GERALD	ESCORT & DISPOSAL DET
MSGT	MULDROW	JEFFERY	96TH WING WEAPONS SAFETY OFFICE
MR.	MURPHY	DAVID	LOCKHEED MISSILES & SPACE COMPANY, INC.
MR.	MURPHY	THOMAS	DEFENSE CONTRACT MGMT DISTRICT WEST
MR	MURTHA	ROBERT	NAVAL CIVIL ENGINEERING LABORATORY
MR.	MYERS	PAUL-REGIS	JOHN HOPKINS UNIVERSITY

MR.	NANCE	WILLIAM	NANCE & ASSOCIATES
MS.	NAPADENSKY	HYLA	NAPADENSKY ENERGETICS, INC.
MR.	NARVER		999 TOWN & COUNTRY ROAD
MR.	NASH	JOHN	OFFICE OF ASST SECRETARY OF ARMY
MSGT	NASH	KEITH	ARNOLD AFB
MR.	NEEDHAM	CHARLES	S-CUBED, A DIVISION OF MAXWELL LABS
MR.	NEFF	RONALD	MILAN ARMY AMMUNITION PLANT
MR.	NEIDERBERGER	GARY	NAVAL WEAPONS STATION
MR.	NEIGHBORS	WILLIAM	GENCORP AEROJET ELECTRONIC SYSTEMS
CWO4	NEILL	STEPHEN	EODMU TWO DET YORKTOWN
MR.	NEWBERN	ROBERT	
MAJOR	NEYRINCK	RONNY	ARSENAAL MATERIEEL&MUNITIE
MR.	NICKERSON	HOWARD	NAVAL FACILITIES ENGINEERING COMMAND
MR.	NICOL	WILLIAM	CHIEF OF NAVAL OPERATIONS
MR.	NOEL	THOMAS	MASON & HANGER SILAS MASON CO., INC.
MR.	NOEL	LLOYD	NAVAL WAPONS STATION, SEAL BEACH
MR.	NORTUNEN	LARRY	US ARMY DEFENSE AMMO CENTER & SCHOOL
MR.	O'BLENESS	ROBERT	BERGSTROM AFB
MR.	O.	GREGORY	USA CHEMICAL RESEARCH COMMAND
MR.	ODELLO	ROBERT	NAVAL CIVIL ENGINEERING LABORATORY
LT.COL	ODENBRING	TOR	SWEDISH DEFENCE MATERIAL ADMINISTRATION
MR.	OEI	SU CHEOK	DEFENCE MATERIALS ORGANIZATION
MR.	OHLSON	JOHNNY	DYNASAFE AB
MR.	OIOM	HANS	ARMY MATERIEL COMMAND
MAJOR	OLSON	LEONARD	CRANE ARMY AMMUNITION ACTIVITY
MR.	OPEL	ALAN	ALPHEUS CLEANING TECHNOLOGIES
MR.	OSWALD	CHARLES	SOUTHWEST RESEARCH INSTITUTE
MR.	OWENS		ATTN: FKSF, UNIT #15230
MR.	PACQUING	LEONARD	DEFENSE CONTRACT MGMT DISTRICT WEST
MR.	PAPE	RONALD	IIT Research Institute
MR.	PAPP	A.	BATTELLE PANTEX
MR	PARK	LUINDE	LAKE CITY AAP
MR.	PARKES	DAVID	BLACK & VEATCH

MS.	PASCAL	SYLVIANE	AEROSPATIALE
LCDR	PASTORICK	JAMES	IT CORPORATION
MR.	PASTRNAK	JOHN	LAWRENCE LIVERMORE NATIONAL LABORATORY
MR.	PATRICK	GWYN	US ARMY TEST & EVALUATION COMMAND
MR.	PELTIER	MICHAEL	DCMAO TWIN CITIES
MR.	PEREA	AARON	ATTN: PL/WSB
MR.	PEREGINO	PHILIP	BALLISTIC RESEARCH LABORATORY
MR.	PEREZ	ANTHONY	DAY & ZIMMERMANN
MR.	PESKO	MICHAEL	STRESAU LABORATORY, INC.
MR	PETERS	CHARLES	US ARMY, ARDEC
MR	PETERSON		DEMEX
MR.	PEZESHK	ALI	THE RALPH M. PARSONS COMPANY
MS.	PH-THEODULE	HELEN	US ARMY MATERIAL TECHNOLOGY LABORATORY
MR.	PHILLIPS	HERMAN	US DEPARTMENT OF ENERGY
CAPTAIN	PHILLIPS	PETER	DEPARTMENT OF DEFENSE
MR.	PHILLIPS	GEORGE	MARINE CORPS SYSTEMS COMMAND
MR.	PIER	DAVID	MP ASSOCIATES, INC.
CAPT	PINHEIRO	JOSE	COMANDO LOGISTICO E ADMINISTRATIVO
MR.	PIPER	CHARLES	QUANTIC INDUSTRIES
MR	PITTS	LARRY	WRIGHT LABORATORY/ARMAMENT DIRECTORATE
MR.	POJMANN	DAVID	OLIN CORPORATION
MR.	POLCYN	MICHAEL	SOUTHWEST RESEARCH INSTITUTE
LCDR	POLIZZI	JOHN	NAVAL AIR WEAPONS STATION
MR.	PONSONBY	MRAK	ATLAS ENVIRONMENTAL SERVICES
MR.	POPE	ALVIN	MASON & HANGER ENGINEERING INC.
MR.	POULAIN		COMMISSARIAT A L ENERGIE
MR.	PRATT	WILLIAM	MISSILE TARGETS
MR.	PRESTON	H.	STRATEGIC WEAPONS FACILITY PACIFIC
MR	PRICE	WILLIAM	VITRO CORPORATION
MR.	PROPER	KENNETH	US ARMY DEFENSE AMMO CTR & SCHOOL
MR.	PUDENZ	PAUL	NAVAL WEAPONS STATION
MR.	PURVIS	JAMES	80 SPACE WING 30 SPW/SES
MR.	QUINN	KEITH	SSI SERVICES, INC.
MS.	QUINTANA	ROXANNE	NAVAL AIR WARFARE CENTER -
MR.	RABUS	HEINRICH	ARMEE MATERIAL OFFICE, GERMANY

MR.	RADFORD	C	Military Traffic Management Command
MR	RAGAN	ELMER	906 FG 906/SEW
CWO3	RAMSEY	EDWARD	NAVAL AIR WEAPONS STATION
MR.	RANKIN	JOHN	US ARMY MATERIEL COMMAND
MR.	REBBY	RAYMOND	ATLANTIC DIVISION - NAVAL FACILITIES
MR.	REDMOND	BEN	EODT SERVICES, INC
MR.	REED	JACK	JWR, INC.
MR.	REEVES	HARRY	NEW MEXICO INSTITUTE OF MINING
MR.	REEVES	JOHN	WEAPONS STATION CONCORD
MR.	REILLY	WILLIAM	ASC/YQI
MR.	RENTER	LAVERN	DEFENSE CONTRACT MGMT DISTRICT WEST
MS.	REYES	BERNADETTE	SAFETY CONSULTING ENGINEERS, INC.
MR.	REYNOLDS	SKIP	IWGERSOLL RANO WATERJET
MR.	RHEA	RICHARD	OLIN CORPORATION
MR.	RHODES	JOHN	THIOKOL CORPORATION
MR.	RICH	MAX	SAFETY ENGINEERING
MR.	RICHARDSON	DAVID	HERCULES, INC.
MR.	RIEF	GEORGE	AIR FORCE FLIGHT TEST CENTER
MR.	RILEY	WILLIAM	30 SPACE WING
MR.	RINARD	GEORGE	GR ASSOCIATES
MR.	RISE	RONALD	NATIONAL TECHNICAL SYSTEMS
MR.	RISING	MERRILL	TECHNICAL ANALYSIS, INC.
MR.	RIVERS	DOUG	3M
MR.	ROBB	DAVID	HQ AFRES/SEV
MR.	ROBEY	ROBERT	NEW MEXICO ENGINEERING RESEARCH LAB
MR.	ROBINSON	RALPH	FIELD COMMAND
MR.	ROBSON	WILLIAM	AEROJET ASRM DIVISION
LTCOL	ROGER	MICHEL	KINISTERE DE LA DEFENSE-DCG-STBFT
MR.	ROLLINS	CHARLES	OLIN ORDNANCE
MR.	ROMAN	BOBBY	AEROJET ELECTRONIC SYSTEMS DIVISION
MR.	ROSADO	ROBERTO	OLIN ORDNANCE
MR.	ROSBERG	ALT	THE NATIONAL INSPECTORATE OF
MS.	ROSENBERG	DIANE	DEFENSE CONTRACT MGMT DISTRICT WEST
MR.	ROSENOW	JOHN	Sandia National Laboratories
MR.	ROSSI	ROBERT	PROJECT MANAGER- AMMO LOGISTICS
MR.	ROUZES	GILLES LE	ICI MCMASTERVILLE
MR.	RYTZ	HANSJOERG	MOD, DEFENSE TECHNOLOGY & PROCUREMENT

MR.	SACI	AVIGDOR	ISRAEL MILITARY INDUSTRIES LTD (IMI)
MR.	SAGE	THOMAS	CORPS OF ENGINEERS
MR.	SALZMAN	PAUL	TRW SPACE & DEFENSE
MR.	SAM NGOO1	YIM SANG	EXPLOMO TECHNICAL SERVICES PTE LTD.
MR.	SAMS	DOUG	AEROJET ASRM DIVISION
MR.	SANTA CRUZ	LAVION	WYLE LABORATORIES
MR.	SAUARIEGO	MEIR	IEOD ENGINEERING LTD.
MR.	SAWYER	RAY	DDESB
MR.	SAYLORS	JAMES	FERRO - SAYLORS, INC
MS.	SCHAFF	MICHELE	ACCUDYNE CORPORATION
LTCOL	SCHAICH	EBERHARD	MATERIALAMT DER BUNDESWEHR 1V 1
MR.	SCHIPMAN	JOSEPH	NAVAL WEAPONS STATION
MR.	SCHMIDT	JOHN	US ARMY MISSILE COMMAND
MR.	SCHNEIDER	GILBERT	NAVAL SURFACE WARFARE CENTER
MR.	SCHOOLER	JAMES	RED RIVER ARMY DEPOT
MR.	SCHUM	ROBERT	DCMAO TWIN CITIES
MR.	SCOTT	JOHN	TEXAS INSTRUMENTS, INC.
MR.	SCOTT	RICHARD	ALLIED SIGNAL
MR.	SEIWELL	ROBERT	WEBB, MURRAY & ASSOCIATES, INC.
MR.	SERENA	J.	U.S. ARMY ENGINEERING DIVISION
COL	SEXSTONE	P.	SECRETARY ESTC
MR.	SHAH	DINESH	R.M. PARSONS COMPANY
MR.	SHANHOLTZ	ERIC	542 SG/MST
MR.	SHATTUCK	MILTON	US ARMY YUMA PROVING GROUND
MR.	SHAW	DOUGLAS	DEFENSE CONTRACT MANAGEMENT AREA
MAJOR	SHEEHAN	CHARLES	103D FIGHTER GROUP
MR.	SHOPHER	KENNETH	
MR.	SHRIVER	JERRY	DEFENSE CONTRACT MANAGEMENT DISTRICK
MS.	SICHON	ALBERTA	
MR.	SIMMONS	LARRY	LAWRENCE LIVERMORE NATIONAL LABORATORY
MGYSGT	SIMMONS	FRANKLIN	EOD SECTION, HQS & SERVICE COMPANY
MR.	SINGH	ASHOK	CRSS ARCHITECTS, INC.
MR	SMITH	LAWRENCE	US ARMY ARMAMENT MUNITIONS &
MR.	SMITH	KENNETH	STRESAU LABORATORY, INC.
MR.	SMITH	SAMUEL	ALLIANT TECHSYSTEMS, INC.
MR.	SMITH	DENNIS	MARTIN MARIETTA AEROSPACE
MR.	SMITH	ROGER	FIELD COMMAND, DEFENSE NUCLEAR AGENCY
MR.	SMITH	DAVID	DEPARTMENT OF ENVIRONMENT UK

MR.	SMITH	STEVEN	US ARMY MISSILE COMMAND
MR.	SNOW	RANDY	THE RICHWAY GROUP
MR	SOLEAU	EDWARD	LTV AEROSPACE & DEFENSE COMPANY
MR.	SONG	SO-YOUNG	AGENCY FOR DEFENSE DEVELOPMENT/KOREA
MR.	SORENSEN	HENRIK	NAVAL MATERIEL COMMAND, DENMARK
MR.	SORRENTINO	LEONARD	HQ AIR MOBILITY COMMAND
LCL	SOUCHET	GILBERT	FRENCH AIR FORCE
MR.	SPAHN	LARRY	MARTIN MARIETTA MISSILE SYSTEMS
MR.	SPEER	HAROLD	NORTHORP
MR.	SPENCE	JOHN	OLIN ORDNANCE CORPORATION
CWO2	SPENCER	PAUL	EOD MALS-16 MAG-16
MR.	SRAMEK	CARL	HOLMES & NARVER, INC.
MR.	STANLEY	GEORGE	OLIN CORPORATION
MR.	STANLEY	CHARLES	NAVAL AIR WEAPONS STATION
MR.	STARTZELL	GREG	THIOKOL CORPORATION
MR.	STAYTON	LEROY	NAVAL AIR WARFARE CENTER WEAPONS DIV
MS.	STERANKA	PAT	PUEBLO DEPOT ACTIVITY
MR.	STEVENSON	RANDY	NORTHROP CORPORATION
TSgt	STEWART	DANIEL	314 AW/SEW
MR.	STINCIC	THOMAS	SENECA ARMY DEPOT
MR	STRATMAN	GEORGE	OGDEN AIR LOGISTICS CENTER (AFLC)
MS.	STUCKEY	BEVERLY	LONE STAR ARMY AMMUNITION PLANT
MR.	STUDDERT	WILLIAM	U.S. ARMY MATERIEL COMMAND
MR.	SUMMERS	RICHARD	DEFENSE CONTRACT MGMT DISTRICT WEST
MR	SUTHERLAND	JOHN	MARTIN MARIETTA ASTRON. GROUP
MR.	SWANEY	DANIEL	THIOKOL CORPORATION
MR	SWANSON	NORMAN	HURLBURT FIELD
MR.	SWANSON	KEITH	834 AIR BASE WING/SEW
MR.	SWINDALL	TERRELL	U.S. ARMY MISSILE COMMAND
MR	SWISDAK	MIKE	NAVAL SURFACE WARFARE CENTER
GROUP CAPT	SYMONDS	PETER	DEPUTY DIRECTOR
MR.	TALLEY	GARY	THIOKOL CORPORATION
MR.	TANCRETO	JAMES	NAVAL CIVIL ENGINEERING LABORATORY
MR	TATOM	FRANK	ENGINEERING ANALYSIS INC.
MR.	TAYLOR	JOYNER	NEW MEXICO INSTITUTE OF MINING
MR.	TEO	KIAN	CDC CONSTRUCTION & DEVELOPMENT PTE LTD

MR.	THOMAS	JOSEPH	HAWTHORNE ARMY AMMUNITION PLANT
MR.	THOMPSON	JOSEPH	THIOKOL CORPORATION
MR.	THOMPSON	N.	21ST SPACE WING
MR.	THOMPSON	LEROY	U.S. DEPARTMENT OF ENERGY
SFC	THORSCN	DONALD	ESCORT & DISPOSAL DETACHMENT
MR.	TIBBITTS	WILLIAM	JET PROPULSION LABORATORY
MR.	TINKLER	WILLIAM	W.S.N. TINKLER
MR.	TOMINACK	JOHN	NAVAL SURFACE WARFARE CENTER
MR.	TOMLIN	MAX	US ARMY STRATEGIC DEFENSE COMMAND
MR.	TORMA	STEVEN	OLIN ORDNANCE
MR	TRIPP	BRIAN	351 MW/SEP
MR.	TSCHRITTER	KEN	SANDIA NATIONAL LABORATORY
MS.	TUCKER	BARBARA	DEFENSE PLANT REPRESENTATIVE OFFICE
MR	TUOKKO	SEPPO	MINISTRY OF DEFENSE
MR.	TWING	CHARLES	U.S. ARMY CORPS OF ENGINEERS
MR.	TWISDALE	LAWRENCE	APPLIED RESEARCH ASSOCIATES, INC.
CAPTAIN	ULSHAFER	MICHAEL	PHILLIPS LABORATORY
MR.	URSERY	ALBERT	DPRO HERCULES
MR.	USKIEVICH	RAY	NAVAL FACILITIES ENGINEERING COMMAND
MR.	VAIDYANATHAN	H.	DEPARTMENT OF NATIONAL DEFENSE
MR.	VAN EVERDINK	LEO	MTMC EUROPE
MR.	VAN EVERY	DESHA	NORTHROP CORPORATION
MR.	VAN RIPER	ED	U.S. ARMY BALLISTIC RESEARCH LABORATORY
MR.	VASELICH	RAYMOND	NASA
MR.	VEZINA	REMI	SNC INDUSTRIAL TECHNOLOGIES, INC.
MR.	VICK	C.	ATLANTIC RESEARCH CORPORATION
MR.	VICKERS	MARVIN	NAVAL SEA SUPPORT CENTER, PACIFIC
MR.	VICTOR	ANDREW	VICTOR TECHNOLOGY
MS.	VINEY	FRAN	DEFENSE CONTRACT MGMT DISTRICT WEST
DR	VRETBLAD	BENGT	FORT F - ROYAL SWEDISH -
MR.	WAGER	PHILLIP	NAVAL CIVIL ENGINERING LABORATORY
MR.	WAGMAN	JAMES	PL/SEW
MR.	WAGNER	WILLIAM	HERCULES INC.
MR.	WALDMAN	BENJAMIN	US ARMY PRODUCTION BASE
CMSGT	WALKER	JOHN	919 SOW/MAEWM

CAPTAIN	WALLACE	DAVID	CHAIRMAN, DOD EXPLOSIVES SAFETY BOARD
MR	WALSH	JAMES	NAVAL ORD MISSILE TEST STATION
MR.	WALTERS	JAMES	US ARMY NUCLEAR AND CHEMICAL AGENCY
MR.	WANCZYK	GLEN	PMOSSP
DR.	WARD	JERRY	DDESB
MR.	WARSHAUR	KEN	MARTIN MARIETTA ELECTRONIC
MR.	WARWICK	WAYNE	LOCKHEED MSD
MR.	WATANABE	WALLACE	US ARMY CORPS OF ENGINEERS
MR.	WEBSTER	LARRY	DDESB
MR.	WEE	TERRY	CHARTERED INDUSTRIES
MR.	WENDEL	CLIFFORD	AMXRM-SHE
MR.	WHEELER	RONALD	SSI SERVICES, INC.
MR.	WHITE	CHARLES	HQ AFSOC/SEW
MAJOR	WIJDEMANS	JAN	MOD/R. NETHERLANDS AIR FORCE
MR.	WILCOX	ROBERT	HUNTSVILLE DIVISION, CORPS OF
MR.	WILLIAMS	GEORGE	HERCULES, INC.
MR.	WILLIAMSON	G.	HEALTH & SAFETY EXECUTIVE
MR.	WILLIS	RICHARD	NORTHORP CORPORATION
MR.	WILSON	NATHANIEL	ARMAMENT RESEARCH, DEVELOPMENT AND
MR.	WINDSOR	MARVIN	NAVAL AIR WARFARE CENTER
MR.	WINGATE	MARK	OLIN CORPORATION
CAPTAIN	WINTLE	FREDERICK	FIELD COMMAND, DEFENSE NUCLEAR AGENCY
MR.	WISE	DANIEL	U.S. ARMY CHEMICAL RESEARCH DEVELOPMENT
MR.	WITIAK	R.	DCMDS-GBQS
MR.	WOFFORD	KENT	SIERRA ARMY DEPOT
MR.	WOLFGANG	GARY	OLIN ORDNANCE
MR.	WOOD	RANDALL	EG&G MOUND APPLIED TECHNOLOGIES
MR.	WOOD	SCOTT	NAVAL WEAPONS STATION - SEAL BEACH
MR.	WOODSON	STANLEY	U.S. ARMY ENGINEER WATERWAYS
CAPTAIN	WORKMAN	RICKEY	HQ USAF WPNS & TACTICAL CENTER
MR.	WU	DA-LIH	BECHTEL NATIONAL
MR.	WYLIE	ALISTAIR	AUSTRALIAN DEFENCE INDUSTRIES, LTD.
LT COL	WYSOWSKI	JOHN	HQ, AIR COMBAT COMMAND
MR.	YAN HAM	NICK	TNO - DEFENSIEONDERZOEK
MR.	YONKMAN	THOMAS	
MR.	YOUNG	MARVIN	GENCORP AEROJET

MR.	YUHAS	JOHN	TECHNICAL ORDNANCE, INC.
MR.	YUN	CHAD	DEFENSE CONTRACT MGMT DISTRICT WEST
MR.	YUTMEYER	WILLIAM	AMC FIELD SAFETY ACTIVITY
COL	ZAKRZEWSKI	STEPHEN	
MR.	ZAUGG	MARK	TOOELE ARMY DEPOT
MR.	ZEHRT	W.	U.S. ARMY ENGINEERING DIVISION
PROFESSOR	ZHANG	YINLIANG	XIAN MODERN CHEMISTRY RESEARCH
MR.	ZOGHBY	DAVID	ICI EXPLOSIVES ENVIRONMENTAL
MR.	ZUCKERWISE	JEFFREY	DCMAO, SPRINGFIELD